TECHNICAL REPORT 3484

SUPPORTING STUDIES: JANUARY - DECEMBER 1965

REPORT NO. 8

ESTABLISHMENT OF SAFETY DESIGN CRITERIA FOR USE IN ENGINEERING OF EXPLOSIVE FACILITIES AND OPERATIONS

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DECEMBER 1966

PICATINNY ARSENAL
DOVER, NEW JERSEY

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ESTABLISHMENT OF SAFETY DESIGN CRITERIA FOR USE IN ENGINEERING OF EXPLOSIVE FACILITIES AND OPERATIONS

PREPARED
FOR THE
ARMED SERVICES EXPLOSIVES SAFETY BOARD

BY

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DECEMBER 1966

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SUMMARY

The major accomplishments during 1965 were:

1. Design and performance of model scale concrete slab tests.

2. Design and performance of model scale bay tests.

3. Design of Modified Phase C-13 Cubicle Test.

4. Other investigations designed to develop information for weapon storage and wall design data.

The primary purpose of the slab test was to:

1. Establish the explosive quantity range for reinforced concrete.

2. Establish the magnitude of multiple reflections of the blast loads which occur in a cubicle type structure.

3. Establish the validity of scaling.

A total of 66 slab tests was performed -- 47 on a 1/3 scale and 19 on a 1/10 scale -- in 1965. Either strengthened slabs or composite slabs (concrete-sand-concrete) were used having a thickness ranging from one to five feet (full scale equivalent). The explosives were cylindrical Composition B charges ranging in weight from 270 to 2,160 lbs. (full scale equivalent).

The tests indicated that an increase of flexural reinforcement fully developed by shear reinforcement significantly increased the resistance of concrete to blast loads. Further, it showed that sandwich type construction appeared to be an improvement over conventional concrete construction -- particularly in areas where large charges were used and where the prevention of spalling was an important factor. It also showed that the presence of side walls (simulating cubicle type construction) significantly increased the blast loads acting on a wall because of reflections. Finally, it indicated the similarity of damage between the 1/10 scale and the corresponding 1/3 scale slab tests. The validity of scaling was demonstrated for the range of charge weights and configurations tested.

The purpose of the Bay Scaling Tests was to evaluate the explosive capacity of a prototype bay structure designed to withstand the blast effects of 2,000 lbs. of high explosives (HE) and to establish the scaling factors that will relate the test results of a given scale model structure to results of a full-scale structure (prototype).

The full-scale prototype bay (40 feet long, 20 feet deep and 10 feet high) comprised a floor slab, a back wall and two side walls. Each wall was of sandwich type with an overall thickness of eight feet (two feet concrete, four feet sand and two feet concrete). The bay dimensions and the reinforcement were scaled in accordance with the geometric scaling laws discussed in Reference 1.

Tests were performed on 1/10, 1/8, 1/5 and 1/3 scale models. For 1/3 and 1/5 scale tests, strain and deflection gages were used to record the mechanism of dynamic wall response (strain and deflection time history) under shock loading. The explosive load (bare spheres) ranged from 2,000 to 7,500 lbs. full-scale equivalent.

Test results clearly demonstrated the validity of scaling in all tests with comparable equivalent charge weights. The structure withstood the 2,000 lbs. equivalent charge and it was shown that it could withstand a much heavier load than 2,000 lbs. before it reached the incipient failure condition.

A modified 1/3 scale version of C-13 cubicle (Reference 11) was designed to demonstrate the use of a new design and construction techniques developed in component testing for highly reinforced concrete and sandwich type cubicle storage facility.

A steel protective cylinder test was run to provide qualitative information on possible improvement of storage cubicles by the addition of a steel cylinder in the cubicle. The results were negative.

Fourteen additional full-scale weapon-to-weapon propagation tests were conducted to evaluate the compartmenting of earth-covered igloos to prevent propagation between weapons in storage using mock-up weapons.

Under Picatinny Arsenal's technical supervision, work was initiated on investigation of various materials for attenuation of HE blast effects. This phase of the overall program is being done by the Office of the Chief of Engineers Waterways Experimental Station, Jackson, Mississippi.

Work began on developing design procedures for reinforced concrete structures utilized in explosive storage and manufacturing facilities.

New impulse curves in the cubicle type structures were developed based -- in addition to theoretical studies -- on slab test results, and confirmed by impulse tests conducted at U. S. Naval Weapons Laboratory (NWL), Dahlgren, Virginia.

Work was initiated to determine, experimentally, the sensitivity of explosive warheads when subjected to multiple blast over-pressures.

An outline of the overall program is in Figure 1 and Tables 1-9.

TABLE 1

SUMMARY OF WALL RESPONSE TEST PROGRAM

Test	Purpose	Status
Full Scale Cubicle Tests	To find storage limit for existing construction.	Completed.
Scaled Slab Tests 1/3 scale reinf. concrete and composite construction	Reduced scale tests of wall design. Establishment of explosive capacity of concrete walls using reinforcing in different design and amounts and composite slabs of concrete-sand-concrete.	In progress.
Model Scale Tests (other than 1/3 scale) with reinf. concrete	To establish validity of scaling.	In progress.
Model Scale Structural Steel and other materials	To establish the explosive capacity of steel and composite walls using various attenuating materials and experimental designs.	Tenative designs; to be tested in FY67.
Scaled Bay Tests 1/3 Scale Bay Test 1/5 Scale Bay Test 1/8 Scale Bay Test 1/10 Scale Bay Test Full Scale Bay Test	To apply newly developed principles of dividing wall construction to a specific design problem and to investigate the validity of scaling.	 Completed 11/65. Completed 11/65. Completed 12/65. Completed 12/65. Under construction, to be tested 6/66.
Modified 1/3 Scale C-13 Cubicle Test	To apply new design principles to a configuration previously tested using standard wall construction.	Construction completed, to be tested 4/66.
Development of Design Chart for Explosive Facilities	To prepare design charts for general use in construction of explosive facilities.	Planned; to be completed in FY67.

TABLE 2

ONE THIRD SCALE REINFORCED CONCRETE SLAB TESTS

Test	Purpose	No. of Rds.	Status
Semi-Quantitative A. Scaling Investigation Test Series No. 1 B. Scaling Investigation Test Series No. 2	Evaluation of testing methods and validity of one-third scaling.	11 6	Completed 10/63 Completed 1/64
C. Camera Coverage Test Series No. 1	Evaluation of methods for photography of fragments.	3	Completed 2/64
D. Slab Response Test Series No. 1 E. Slab Response Test Series No. 2 F. Slab Response Test Series No. 3 G. Slab Response Test Series No. 4	a. To establish the explosive quantity range for specially reinforced concrete. b. To establish a general configuration of reinforced concrete (plain, composite, etc.) which will be used in the construction of explosive facilities. c. To evaluate the blast loading (impulse) applied to the wall (Al. plugs used to measure impulse).	13 19 16 24	Completed 6/64 Completed 4/65 Completed 12/65 To be completed 4th Qtr FY66
H. Equivalent Charge Test Series No. 1	a. To establish the magnitude of multiple reflections of blast load which occur in a cubicle type structure. b. To establish testing procedures by which the damage resulting from an explosion in a cubicle can be evaluated in terms of slab damage.	12	Completed 4/65
I. Scaling Investigation Test Series No. 3	To test identical 1/3 scale and full scale slabs to evaluate validity of scaling	8	Slabs fabricated, test scheduled for 1st Qtr FY67
Quantitative Series	Development of design standards for reinforced concrete walls.	To be determined	Test design in progress, to be tested 1st & 2nd Qtr FY67

TABLE 3

MODEL SCALE STRUCTURAL STEEL AND OTHER MATERIALS

(OTHER THAN CONCRETE)

Test	Purpose	No. of Rds.	Status
Semi-Quantitative A. Slab Response Series No. 1	Semi-quantitative evaluation of response of various design structural steel slabs to relatively small charges.	10	Designs of slabs completed. Testing scheduled for 2nd Qtr FY67
B. Slab Response Series No. 2	Semi-quantitative evaluation of best designs resulting from "A" using larger charges.	To be determined	Future
C. Scaling Investigation Test Series	To determine the validity of scaling for structural steel slabs.	To be determined	Future
New Materials Evaluation Test Series (WES)	To investigate new blast attenuating materials as fillers in composite construction.	30	Design completed. Test scheduled for 4th Qtr FY66
One-third Scale Steel Cylinder Test No. 1	To qualitatively test proposed designs by NOL for increased capacity of existing storage bays.	3	Completed 1/65
One-third Scale Steel Cylinder Test No. 2		To be determined	Additional test anticipated in FY67
One-third Scale Fibrous Reinforced Slabs	To evaluate use of fibrous reinforcing developed by the Ohio River Div. OCE in combination with PA designs.	4	Designs in progress. Test scheduled for 4th Qtr FY66

TABLE 4

SMALL SCALE REINFORCED CONCRETE SLABS (1/10, 1/8, 1/5)

Test	Purpose	No. of Rounds	Status
1/10 Scale Calibration Tests	To develop the technique of measuring fragment velocities	5	Completed 8/65
1/10 Scale Scaling Investigation Tests	a. To establish the validity of scaling. b. To establish quantity range for reinforced concrete (plain & composite construction). c. To evaluate the economy of small scale testing	14	Completed 10/65
1/8 Scale Scaling Investigation Tests		20	Slabs fabricated. Tests scheduled for 3rd Qtr FY66
1/5 Scale Scaling Investigation Tests		15	Slabs being fabricated. Tests scheduled for 4th Qtr FY66
1/10 Scale Static Tests	a. To determine static resistance-deflection characteristics of the slabs. b. To establish relationship between dynamic and static responses of slabs.	5	Slabs fabricated. Tests scheduled for 4th Qtr FY66
1/8 Scale Static Tests		5	Slabs fabricated. Tests scheduled for 4th Qtr FY66
1/5 Scale Static Tests		5	Slabs being fabricated. Tests Scheduled for 4th Qtr FY66

TABLE 5

SCALED BAY TESTS

Test	Purpose	No. of Rounds	Status
1/10 Scale Bay	a. To evaluate the explosive capacity of a specific bay structure to withstand the blast effect of 2,000 lbs. Full Scale Equivalent of High Explosives. b. To establish model factors which will relate the results of a given scale model structure to results of a full scale structure.	3	Completed 8/65
1/8 Scale Bay		4	Completed 10/65
1/5 Scale Bay		3	Completed 10/65
1/3 Scale Bay		3	Completed 11/65
Full Scale Bay		3	Design completed. Tests scheduled for 4th Qtr FY66
1/10 Scale Bay	To estimate the ultimate explosive capacity of the bay.	1	Scheduled 1/66
Modified 1/8 Scale Bay		1	Structure completed. Test scheduled for 4th Qtr FY66
Modified 1/8 Scale Bay (Plain Concrete)	To evaluate the use of plain reinforced concrete as compared to composite construction.	3	Design in progress. Tests scheduled for 1st Qtr FY67

TABLE 6

MODEL SCALE CUBICLE TESTS

Test	Purpose	No. of Rounds	Status
1/3 Scale Cubicle Test Modified C-13	To further demonstrate the use of new design standards and construction methods for highly reinforced type cubicle storage facilities. To evaluate the feasibility of tying walls together as a variation in wall design.	1	Design completed. Construction in progress. Test scheduled for 4th Qtr FY66
1/8 Scale Confirmatory Cubicle Designs	To confirm design charts developed as result of 1/3 scale quantitative slab test series.	25 (Est.)	To be selected when design charts are available. Scheduled for FY67
Modified ADC Cubicle Test	To investigate the feasibility of strengthening existing ADC cubicles to increase storage capacity		Feasibility study prepared.

TABLE 7

PREPARATION OF DESIGN CHART FOR EXPLOSIVE FACILITIES

Title	Purpose	Status
Blast-Impulse Loads in a Cubicle Type Structure	Preparation of working charts for use in the determination of blast loads to be utilized in the design of cubicle type construction	Work initiated and scheduled to be completed 3rd Qtr FY67
Impulse-Load Capacity of Reinforced Concrete Cubicle Type Structures	Preparation of working charts for use in the determination of the reinforced concrete walls to be utilized in the design of cubicle type structures	Planned. To be completed in the 4th Qtr FY67

TABLE 6

WEAPONS EFFECTS INVESTIGATION

Impulse Tests Using Plug Arrangement	To investigate reflected impulses in a cubicle type structure with non-frangible and partly frangible roof.	Test design in progress. Tests scheduled for 2nd Qtr FY67
Spring Arrangement Impulse Measurement Method	To obtain the impulse loads in a cubicle type structure and to evaluate reflection effects.	Test structure being planned.

TABLE 9

ACCEPTOR SENSITIVITY PROGRAM

Tests	Purpose	Status
Primary Fragment Impact	Evaluate sensitivity of cased and uncased charges to attack by fragments from adjacent explosive charges.	Theoretical studies completed. Firing tests against uncased charges completed (Report issued 1/66). Firing tests against cased charges planned for 4th Qtr FY67.
Secondary Fragment Impact	To investigate sensitivity of various explosive charges to impact of secondary fragments (rubble, sand) resulting from wall break-up.	Method developed for firing rubble and sand at controlled velocities. Propagation threshold velocity for cyclotol established. Tests to obtain additional information on other explosives, casing and anchorage is in progress. To be completed 4th Qtr FY67.
Sensitivity of "Weapon-to-Weapon Propagation Test" configuration	To evaluate the relative sensitivity of different weapons used in the "Weapon-to-Weapon Propagation Tests" to blast overpressure.	Calibration test in progress. Weapon tests scheduled for 1st Qtr FY67.

SECTION 1

SCALED SLAB TESTS

INTRODUCTION

The slab test series were initiated to provide as economically as possible information on structural response of reinforced concrete and composite dividing walls. Several test series were performed prior to December 1964 for the initial assessment of the explosive quantity range characteristics of concrete and composite slabs, and for development of a method of accurately measuring the structural response of model slabs in terms of fragment velocities. A total of three test series were performed prior to December 1964.

During 1965, these tests were continued for the basic purpose of obtaining data which could be used in the formulation of design procedures. Tables 10-12 showing three test series -- two wall response tests and one equivalent charge test series -- were performed on a 1/3 scale.

Because of overlapping, in several instances, the 1/3 scale tests will be discussed chronologically rather than according to their specific objectives.

As part of the scaling study, a series of smaller scale slab tests also were initiated. The 1/10 scale model tests were completed and are presented in comparison with results for equivalent 1/3 scale models.

1/3 Scale Slab Tests

Three test series were conducted in 1965:

Slab Response Test Series 2
Slab Response Test Series 3
1/3 Scale Equivalent Charge Test Series 1

The purpose of Slab Response Test Series 2 and 3 was to:

1. Establish a general configuration of reinforced concrete (plain, composite, etc.) which will be useful in the construction of explosive facilities.

TABLE 10

ONE-THIRD SCALE RESPONSE TEST SERIES No. 2

No.	Rd. No.	Type Slab (See Table	Charge Properties[1] W lbs.	R in.	Z_A ft/lbs$^{1/3}$	Equiv Full Scale Chg. Wt. (lbs)	Type[2] Cubicle Z_B/Z_A	Type[3] Damage	Fig. No.	Results
1	14/1	Std. #3	10	38	1.5	270	None	TD	13	Diagonal failure and reinforcement rupture.
2	2/1	Str. #2	10	13	0.5	270	None	TD	14	Disintegration of center of slab. Diagonal failure.
3	1/1	Str. #2	10	32	1.25	270	None	HD	15	No reinforcement failure. Several major cracks, spalling at the acceptor face.
4	4/1	Str. #3	10	13	0.5	270	None	HD	16	No reinforcement failure. Slab bent into two sections.
5	3/1	Str. #3	10	32	1.25	270	None	HD	17	No reinforcement failure. Damage similar to No. 3.
6	5/1	Str. #4	10	13	0.5	270	None	HD	18	No reinforcement failure. Damage similar to No. 4 but somewhat less (no folding of slab).
7	6/1	Str. #4	20	16.5	0.5	540	None	TD	19	Disintegration of center of slab. Diagonal failure and positive reinforcement rupture.
8	9/1	Str. #5	20	16.5	0.5	540	None	PD	20	Positive reinforcement failure. Donor reinforcement intact. Concrete crushed in the center of slab.
9	8/1	Str. #6	20	41.5	1.25	540	None	MD	21	Reinforcement intact. Minor spalling on acceptor face.
10	12/1	Str. #7	20	16.5	0.5	540	None	TD	22	Diagonal failure and reinforcement rupture. Center completely shattered.
11	11/1	Str. #8	30	18.5	0.5	810	None	HD	23	Reinforcement intact. Several cracks penetrating depth of slab. Deep spalling of acceptor face.
12	7/1	Comp. #2	20	16.5	0.5	540	None	MD	24	Tension cracks in acceptor panel. Major damage of donor panel.
13	10/1	Comp. #3	30	18.5	0.5	810	None	MD	25	Reinforcement intact. Several major cracks in acceptor panel. Few spalls in the tunnel. Partial damage to donor panel.
14	13/1	Comp. #4	30	15	0.4	810	None	LD	26	Tension cracks in acceptor panel. Damage similar to No. 12.
15	16/1	Comp. #5	30	18.5	0.5	810	1.0	LD	27	All reinforcement intact. Spalling of both panels. Heavier damage to donor panel.
16	18/1	Comp. #6	30[4]	15	0.4	810	1.0	LD	28	Slight tension cracks in acceptor panel. Major damage of donor panel.
17	19/1	Comp. #6	40[4]	20.5	0.5	1080	None	LD	29	Hairline tension cracks in acceptor panel. Heavier damage to
18	15/1	Comp. #7	30	18.5	0.5	810	1.25	TD	30	Slab broken into large sections thrown through the tunnel.
19	17/1	Comp. #8	30	18.5	0.5	810	1.25	LD	31	Tension cracks in all 3 slabs. Some crushing of the center and donor panels. Reinforcement intact.

Abbreviations: Std. - Standard
Str. - Strengthened
Comp. - Composite

(1) W - charge weight (lbs.)
R - Distance from charge to wall in question (in.)
Z_A - $R/W^{1/3}$ (ft/lbs$^{1/3}$)
Z_B - Scaled distance from the center of the cubicle to the adjacent wall.
(2) All rounds with cubicle arrangement simulated the backwall condition.
(3) TD - Total Destruction - Slab broken up producing flying fragments.
PD - Partial Destruction - Slab broken up, but remaining in one piece, (beyond incipient failure).
HD - Heavy Damage - At or around incipient failure condition.
MD - Medium Damage - Less than incipient failure condition, (spalling deflections, cracks).
LD - Light Damage - Appreciably less than incipient failure, (minor cracks, light spalling).
(4) Donors consisted of one 10 lb. + 20 lbs. or two 20 lbs. charges.

TABLE 11

ONE-THIRD SCALE RESPONSE TEST SERIES No. 3

No.	Type Slab	Charge Properties(*) W	R	Z_A	Equiv Full Scale Charge	Type(3) Cubicle Z_A/Z_B(*)	Type(4) of Damage	Fig. No.	Results
1	Str. #10	20	33	1.0	540	None	MD	32	All reinforcement intact. Some spalling of donor and acceptor surfaces. Overhangs not fully developed.
2	Str. #10	20	26	0.8	540	None	MD	33	All reinforcement intact. Spalling on both surfaces. Overhangs developed.
3	Str. #11	20	26	0.8	540	None	PD	34	Tension reinforcement failed at both supports and center. Complete spalling of acceptor surface. Overhangs developed.
4	Str. #11	20	33	1.0	540	None	HD	35	Incipient failure. Failure of tension reinforcement at one support and center of slab (6 bars). Spalling 75% both surfaces. Overhangs developed.
5	Str. #12	20	33	1.0	540	None	PD	36	All tension reinforcement failed (at both supports and center). Shear failure in concrete. Loop reinforcement used produced much weaker slab.
6	Str. #13	30	18.5	0.5	810	None	HD	37	No reinforcement failure. Large deflections. Complete spalling on both sides. Overhangs developed.
7	Str. #13	30	18.5	0.5	810	1.0	HD	38	Tension reinforcement failed at both supports and center (incipient failure). Very heavy deflections at center (11 in.).
8	Str. #14	30	18.5	0.5	810	1.0	MD	39	All reinforcement intact. Complete spalling of acceptor. Overhangs partially developed.
9	Str. 15	60(1)	19.5	0.42	1,620	None	TD	40	Most reinforcement failed. (Slab used to determine velocities of plugs). Slab fragments and dust obscured plugs.
10	Comp. #9	40	20.5	0.5	1,080	None	PD	41	Tension reinforcement failed at both supports and center (donor panel). Tension and compression reinforcement failed at center (acceptor panel). Two deflection gages damaged.
11	Comp. #9	30	18.5	0.5	810	None	HD	42	Reinforcement failed along right support and center (donor panel). Tension reinforcement failed at both supports and center (acceptor panel). (Incipient failure).
12	Comp. #10	60	23.5	0.5	1,620	None	HD	43	Reinforcement failed at both supports (donor panel). All reinforcement intact (acceptor panel). Spalling on donor and acceptor panels. Overhangs fully developed.
13	Comp. #11	60(1)	19.5(2)	0.42	1,620	0.87	HD	44	All reinforcement in both panels (except one tie) intact. Complete spalling of donor and partial spalling of acceptor panels. Slight splitting of overhangs.
14	Comp. #11	80	19.5(2)	0.36	2,160	0.87	HD	45	All reinforcement intact. Overhangs crushed in lower half of slab.
15	Comp. #12	60(1)	17.0(2)	0.36	1,620	0.87	HD	46	All reinforcement intact (except one tie). Heavy spalling and deflection in lower portion.
16	Comp. #12	80	17.0	0.36	2,160	0.87	HD	47	All reinforcement intact. Complete spalling of all surfaces. Splitting of overhangs adjacent to reflection plates.

(*) Glossary: W - charge weight (lbs.)
R - distance from charge to wall in question (in.)
Z_B - scaled distance from center of cubicle to adjacent wall.
Z_A - $R/W^{1/3}$ (ft/lbs$^{1/3}$)

Str. - Strengthened
Comp. - Composite

(1) 6 X 10 lbs. charges were used.
(2) Height from surface to center of charges was 8 inches.
(3) Rounds 7,8,13 and 14 simulated back wall condition of cubicle.
(4) TD - Total Destruction - Slab broken up completely producing flying fragments.
PD - Partial Destruction - Slab broken up but remaining in one piece (beyond incipient failure).
HD - Heavy Damage - At or around incipient failure condition.
MD - Medium Damage - Less than incipient failure condition (spalling, deflection, cracks).

TABLE 12

ONE-THIRD EQUIVALENT CHARGE TEST SERIES No. 1

No.	Rd. No.	Name of Slab	Charge Properties W lbs.	R in.	Z_A ft/lbs$^{1/3}$	Equiv. Full Scale wt.	Type(1) Cubicle Z_B/Z_A	Type(2) of Damage	Fig. No.	Results
1	1/2	Str.#4	20	41.0	1.25	540	0.5	TD	48	Disintegration of concrete
2	2/2	"	20	32.0	1.0	540	0.5	TD	49	Disintegration of concrete
3	3/2	"	20	18.0	0.50	540	0.5	TD	50	Disintegration of concrete
4	4/2	"	20	52.0	1.60	540	0.5	PD	51	Shear failure of concrete
5	5/2	"	20	18.0	0.55	540	0.5	TD	52	Disintegration of concrete and steel
6	6/2	"	20	26.0	0.8	540	0.5	TD	53	Disintegration of concrete and steel
7	11/2	"	20	41.0	1.25	540	0.5	TD	54	Disintegration of concrete
8	9/2	"	20	26.0	0.80	540	1.0	TD	55	Disintegration of concrete and steel
9	7/2	"	20	26.0	0.8	540	1.0	TD	56	Disintegration of concrete
10	10/2	"	20	41.0	1.25	540	1.0	PD	57	Shear failure
11	8/2	"	20	32.0	1.0	540	None	TD	58	Disintegration of concrete
12	12/2	Str.#9	30(3)	16.5	0.4	810	1.17	HD	59	Reinforcement intact. Heavy spalling

Glossary: W - Charge weight (lbs.)
R - Distance from charge to wall in question
Z_B - Scaled distance from the center of the cubicle to the adjacent wall
Z_A - $R/W^{1/3}$

(1) Rounds 5/2, 6/2 and 7/2 simulated side wall conditions, remaining rounds simulated back wall condition of the cubicle

(2) TD - Total Destruction - Slab broken up completely producing flying fragments
PD - Partial Destruction - Slab broken up but remaining in one piece
HD - Heavy Damage - At or around incipient failure condition

(3) Donor consisted of one 20 lbs. + 10 lbs. charges

Abbreviations: Str. - Strengthened

2. Establish explosive quantity range for reinforced concrete.

3. Investigate the use of annealed (high carbon) steel wire to simulate, on a model scale, the ductile properties of the reinforcement commonly used in explosive facility construction.

4. Investigate the optimum amount of reinforcement and the maximum amount of reinforcement that is feasible in cubicle construction.

5. Evaluate specific detailing of reinforcement (various kinds of shear reinforcement, placement of reinforcement).

6. Evaluate approximate testing procedures for future quantitative tests.

7. Evaluate composite construction compared with plain slab construction.

8. Obtain the history of wall deflections (total and permanent) under various load conditions.

9. Make a preliminary evaluation of the effectiveness of the composite wall construction that will be used in the forthcoming modified C-13 cubicle test.

10. Obtain information pertaining to the blast impulse acting on the individual test panels.

The purpose of the 1/3 Scale Equivalent Charge Test Series was to establish the magnitude of multiple reflections of the impulse loads which occur in a cubicle type structure as supplementary data to those obtained from steel cubicle test series (Reference 2).

A total of 35 slabs were tested in the Response Test Series and 12 tests were performed in the Equivalent Charge Test Series during 1965 at the NOTS facility. All tests were performed in a vertical position using either the structural steel tunnel facility or the new reinforced concrete slab support structure. Camera coverage was provided by high speed and still cameras. The majority of plain slabs (non-composite slabs) were provided with aluminum plugs

to permit determination of impulse loads acting on the wall under various load conditions.

Charges used (cylindrical Composition B) ranged from 270 lbs. full scale equivalent (10 lbs. on 1/3 scale) to 2,140 lbs. (80 lbs. on 1/3 scale) located at scaled distances ranging from 0.36 to 1.5 ft/lb$^{1/3}$.

The tests indicated that a substantial increase in wall capacity can be accomplished by strengthening the slab (using a high percentage of reinforcement) and by proper use of reinforcing ties (shear reinforcing) which significantly increased the resistance to blast. The test results also showed that composite type slabs (concrete-sand-concrete) -- using strengthened panels as the concrete portion of these slabs -- appears to be an improvement over plain slab construction because of the blast-attenuating and inertial characteristics of the sand. The equivalent charge test series showed that the presence of side walls (simulating cubicle type construction) significantly increased the blast loads acting on a wall due to reflection factors.

Vertical Support Tunnel

A detailed description of the Vertical Support Tunnel was included in the previous annual report (Reference 3). However, since the majority of slab tests were performed using this facility, its description also will be included in this report.

The facility consists of heavy steel plates embedded in the ground forming a tunnel-like structure. The slabs are supported against an opening in the tunnel wall. Another opening exists at the rear tunnel wall. The bottom edge of the slab is supported on a horizontal steel base plate. The roof of the tunnel and a steel block above the test specimen seals the tunnel, allowing the larger fragments of the test specimen to enter the tunnel while keeping out the dust and flash produced by detonation of a donor charge (Figure 2). A high-speed camera is placed at one end of the steel plate tunnel. At the other end of the tunnel, a searchlight is placed so that the line-of-sight between camera and searchlight coincide with the longitudinal axis of the tunnel and is perpendicular to the travel of the test specimen fragments. The silhouettes of the flying fragments appear against the strong light field in the tunnel.

These are photographed by the high-speed camera. The film record is then analyzed to determine the fragment velocity. This technique was developed to measure fragment velocities without being obscured by the dust cloud from the detonation. A second camera is used to photograph the fragments after they emerge from the tunnel. The line-of-sight for this camera is also perpendicular to the travel of the fragments. The camera faces a backboard marked with vertical lines that form a scale for measuring the flight of the fragments. Complete break-up of the test specimen can be viewed by high-speed camera located about 200 feet in back of the rear face of the test tunnel. This camera records the overall test in addition to details of the break-up of the rear surface of the slab (Figure 3).

Description of a New Slab Support Structure

The tunnel test facility proved to be inadequate for charges over 30 lbs. of HE; a new multi-purpose slab support structure was constructed so that in addition to much higher charge weight capacity, the newer facility would permit greater flexibility in testing arrangement and capacities.

This slab support structure consists basically of three adjacent reinforced concrete blocks aligned longitudinally and interconnected at their bases by means of reinforced concrete pedestals (Figures 4-6). Each block is eight feet long, eight feet wide and nine feet high, and is traversed by a horizontal sighting tube 30 inches in diameter. The length of the concrete structure is 30.5 feet and the overall length (including the sighting tube extension) is 110 feet (Figure 7).

Reinforcement of each block consists of conventional reinforcing bars and structural shaped bars (Figure 8). Two A-frames are embedded in each of the three concrete blocks and extend two feet below the blocks into a two-foot auger hole filled with concrete. 3/8-inch-thick steel plates cover exposed concrete surfaces.

A searchlight is provided at one end of the sighting tube and an adjustable distance scale for measuring fragment velocities is incorporated within the tube. Consisting of two parallel pipes mounted in a movable frame, the adjustable distance scale is so oriented that the pipes are either vertical or horizontal.

Pressure and deflection gage mounts are embedded in all appropriate surfaces together with the related conduits (Figure 9 and 10).

The slab support structure was designed to test various types and sizes of slabs. Slabs can be tested in either horizontal or vertical position, and may be either full-scale slabs or scale models, of plain or composite construction.

To prevent slabs from sliding and to fix the slabs more firmly at their support, four holes were drilled in the support structure at points where slabs are to be bolted to the structure. A detailed description of the support structure is in Reference 4.

Test Set-Up

Items included in the test set-up were:

- Test specimens
- Explosive charge
- Slab support structure
- Photographic and other equipment

The test specimens were either 1/3 scale plain, reinforced concrete or composite (concrete-sand-concrete) slabs. Linear dimensions of the slab (width, length, height) and reinforcing steel were reduced in accordance with the geometric scaling laws. Reinforcing steel was either annealed wire, hot rolled reinforcing bars or combination of both (Table 13).

The explosives used were cylindrical Composition B charges ranging in weight from 10 lbs. (270 lbs. full-scale equivalent) to 80 lbs. (2,140 lbs. full-scale equivalent). All slabs were supported in a vertical position.

As discussed, full coverage of still and high-speed photography was used in most test series. For a few rounds in Slab Response Test Series deflection gages were used. All plain slabs in 1/3 Scale Equivalent Test Series 1 and in Slab Response Test Series 3 were provided with aluminum plugs of known mass, mounted in a steel plate which in turn was cast into or bonded to the surface of the test specimen. The velocities of the plugs emerging from the slab were measured with the help of high-speed cameras to permit the calculation of impulse acting on the wall under various conditions.

TABLE 13

SLAB PROPERTIES

Name of Slab	Slab[1] Thickness (Inches)	Longitudinal Reinforcement % Donor Surface	Acceptor Surface	Stirrups	Type	Slab Span (ft.)
Strengthened #2	4	0.44	0.44	-	wire	2.0
Strengthened #3	4	0.65	0.65	-	bars	2.0
Strengthened #4	4	1.40	0.65	-	bars	2.0
Strengthened #5	4	0.66	0.66	0.15	bars	2.0
Strengthened #6	4	1.40	0.65	0.40	bars	2.0
Strengthened #7	12	0.15	0.15	-	bars	2.0
Strengthened #8	12	1.33	0.69	0.53	bars	2.0
Strengthened #9	13	1.27	0.65	0.53	bars	2.0
Strengthened #10	4	1.40	0.65	0.40	bars	2.0
Strengthened #11	4	0.65	0.65	0.15	bars	2.0
Strengthened #12	4	0.65	0.65	0.30[4]	bars	2.0
Strengthened #13	4	2.7	2.7	1.2	bars	2.0
Strengthened #14	6	2.7	2.7	1.2	bars	2.0
Strengthened #15	4	0.75	0.75	-	bars	2.0
Composite #2	4-six-4	0.65	0.65	-	bars	2.0
Composite #3	4-six-4	0.65	0.65	0.15	bars	2.0
Composite #4	4-twelve-4	0.65	0.65	0.15	bars	2.0
Composite #5	4-six-4	1.4	0.65	0.40	bars	2.0
Composite #6	4-twelve-4	1.4	0.65	0.40	bars	2.0
Composite #7	4-four-4- four-4	0.15[2] 0.25[3]	0.15[2] 0.25[3]	- -	wire	2.0
Composite #8	4-three-4- three-4	0.16[2] 0.65[3]	0.16[2] 0.65[4]	- 0.15	bars	2.0
Composite #9	4-six-4	0.65	0.65	0.15	bars	2.0
Composite #10	4-twelve-4	2.7	2.7	1.20	bars	2.0
Composite #11	6-eight-6	2.7	2.7	1.20	bars	2.0
Composite #12	6-eight-6	2.7	2.7	1.20	bars	3.0

(1) Numbers spelled out indicate thickness of sand filler

(2) Indicates percent reinforcement in the center slab

(3) Indicates percent reinforcement in each of the outside slabs

(4) Loop reinforcement used

In equivalent Charge Test Series 1, the slabs were provided with a single plug located in the geometrical center of the slab. In the Slab Response Test Series 3 the slabs were provided with three plugs (each having a different color for easier indentification) located diagonally across the slab (Figure 11).

In addition, some composite slabs in Response Test Series 3 were provided with deflection gages. The gages used were linear displacement transducers which operate on the principle of change in inductance in the coils of a linear differential transformer with changes in position of the core. The transformer unit was mounted to U-shaped steel supports which in turn were welded to the steel plates attached to the concrete blocks (Figure 12). The information from these gages is the time deflection history of the response of the test panel.

A detailed description of the results of the individual rounds and a detailed analysis will be included in a separate technical report which will be published shortly (Reference 5). Summary tables on 1/3 Scale Slab Tests are in Tables 10-12; slab properties are in Table 13.

Figures 13-59 show the results of slab tests and are cross-referenced in Tables 10-12.

Slab Response Test Series 2

All slabs without shear (ties) reinforcement -- except Round 7/1 -- underwent total or partial destruction (all data concerning the rounds in Slab Response Test Series 2 are in Table 10). In the composite (sandwich) slabs which were not destroyed, the donor panel failed due to the excessive shear stress while the acceptor panel remained intact (because of the relatively small loading). On the other hand, in those slabs where shear (diagonal) reinforcement was provided (both strengthened and composite slabs) the response of the slabs was governed by the capacity of their flexural reinforcement. In these slabs, the damage sustained ranged from light damage to partial destruction. However, the major portion of these slabs sustained light to heavy damage with slab Round 9 failing -- (fracture of positive reinforcement) -- because it was overloaded.

All strengthened slabs which did not fail exhibited spalling of the concrete cover at the acceptor side. As long as flexural reinforcement remained intact (with the shear reinforcement present) spalling of the concrete cover did not penetrate beyond the depth of the main reinforcement.

Unlike the plain (strengthened and standard) slabs, the composite slabs remained intact in most instances with charges as large as 40 lbs. (1,080 lbs. full-scale equivalent) and scaled distances as small as 0.4 ft/lb$^{1/3}$. The one exception was Composite Slab 7 which consisted of five layers, using two standard exterior slabs (Figure 30). As expected, this slab suffered complete destruction. The test demonstrated that the addition of mass (sand) alone while maintaining the light reinforcement (standard slab on the exterior) will not suffice. Therefore, the modification must be achieved with the use of increased strengthened panels. This was demonstrated in the next test in Round 17/1 (Composite Slab 8, Figure 31) where two strengthened exterior slabs were used. The test results indicated that this modified slab could resist a 30-lb. charge located at a scaled distance of 0.5 ft/lb$^{1/3}$ using a simulated cubicle arrangement, while previous modifications (using standard slab outside in place of strengthened slab) failed under similar test conditions.

The other composite slabs showed a remarkable ability to resist the impact of the blast loads even though in some cases the donor panels sustained severe damage. The effectiveness of using shear reinforcement was again demonstrated by comparing Rounds 10/1 and 7/1. Round 10/1 suffered less damage than Round 7/1 despite the fact that Round 7/1 was subjected to less intensified blast load than Round 10/1. This fact should be attributed primarly to the utilization of shear reinforcement in the slab used in Round 10/1. The slabs of Round 16/1 and 17/1 sustained comparatively light spalling of their donor surface (donor panel); the spalling of these slabs was the result of the crushing of the concrete cover due to bending action of the slabs at their center. The donor surfaces of other composite slabs sustained severe spalling. These slabs underwent relatively large deflections --

resulting in the formation of large cracks in the donor surface which in turn resulted in scabbing type spalling. This spalling of the acceptor surface of the donor panel occurred in Round 16/1, 18/1 and 19/1 (Figures 27-29). In Round 16/1, this spalling was the result of the transmission of shock wave through concrete, while the spalling in Rounds 18/1 and 19/1 was caused by the larger deflections and the crack formation at points of high stress concentration (scabbing). Only slab in Round 16/1 exhibited spalling of both surfaces of acceptor and donor panels which was produced by the direct shock transmission.

Conclusion

The strengthening of a reinforced concrete slab either by adding more steel (flexural and shear reinforcement) or more steel in combination with additional mass appreciably increased the capacity of the slab to withstand the blast loads.

The composite type slab using strengthened slabs, in combination with sand, proved to be effective to resist blast loads at close distance ($Z = 0.5$) resulting from up to 1,000 lbs. of HE equivalent charge. The sand in composite slabs was effective in reducing spalling of the acceptor panel. The use of shear reinforcement greatly increased the slab capacity and ductility in resisting blast loads.

The presence of side walls (simulating cubicle type construction) significantly increased the blast loads acting on a slab due to reflection factors.

Discussion of Slab Response Test Series 3

As a follow-up to the Response Test Series 2, this series was designed to investigate the increase in the amount of reinforcement to the practical maximum (2.7%) in wall capacity to blast loads. All data covering the rounds in Slab Response Test Series 3 are in Table 11.

Of the slabs tested, four failed (Rounds 3, 5, 9 and 10). The remainder suffered less than incipient failure for charges as large as 80 lbs. (2,160 lbs. full-scale equivalent) and scaled distances as small as 0.33 ft/lb$^{1/3}$. The tension reinforcement failed in slabs of Rounds 3 and 9 (Figures 34 and 41). In both

cases, failure occurred at points of maximum stress at the supports and at the center of the slab with the remainder of the slab remaining essentially intact. This phenomenon was the result of the presence of the diagonal shear reinforcement which maintains the integrity of each slab between the hinge points after failure. An interesting observation can be made from these results. Because of hinge action of the slabs at their support sections, the slabs tend to swing open as a hinged door instead of being reduced to rubble after failure of reinforcement. Its importance in actual design lies in the fact that if a cubicle wall fails, the sections dislodged will rotate about the hinge supports (compression reinforcement at supports will produce hinge action) and will either crash into the ground or into other portions of the structure still intact -- thereby absorbing most of the overload. Rotation of the wall section in place of translation will occur in walls without shear reinforcement where fragments formed by wall break-up will be propelled at high velocity downstream from the structure.

In strengthened Slab 12 (Round 5) loop stirrups were used in place of diagonal stirrups. The failure was produced by pure shear between the loop stirrups (Figure 36). Therefore, it is apparent that the shear reinforcement must be a continuous one (as in the case of diagonal reinforcement utilized in Round 4).

The slab in Round 9 was used for impulse measurements by inserting 24 aluminum plugs and detonating 60 lbs. (6,620 lbs. full-scale equivalent) at a scaled distance Z = 0.5. Since the slab was grossly overloaded its failure was expected. Because of cloud formation resulting from complete breakup of the slab, no valuable velocity data was obtained from this round. Future impulse measurement tests will be performed using steel plates which will not be destroyed by the blast load.

In this series, restraining plates were placed against the overhangs of the strengthened slabs. The purpose of using these plates was to more fully develop the bending moment capacity of the overhangs than in Slab Response Test Series 2. It was evident from the results of Slab Response Test Series 3 that heavier reinforced strengthened slabs underwent relatively large deflections without failing. This is attributed to the fact that the overhangs of the slabs could slide inward

during the application of the load with a resulting large deflection of the center of the slab. This is demonstrated in Round 6 where a heavily reinforced slab was deflected 11 inches at the center without failure of any of the reinforcing bars (Figure 37). If the slab overhangs had been properly restrained, this large deflection could not have occurred and the horizontal reinforcing bars would have been forced to carry the entire load. This should have resulted in greater damage to the slab.

In a cubicle type structure, this type of restraint was provided by the floor and side walls. It was decided to test subsequent rounds by bolting the overhangs into slab support structure and thus truly simulate the response of a wall in a cubicle arrangement effect of support conditions.

The only composite slab that failed was in Round 10 (Figure 41). The interesting observation was that the same slab in previous series remained intact (Slab Response Test Series 2, Figure 25). The variation in test results can be attributed to higher charge weight (40 lbs. vs. 30 lbs. in previous test), the absence of shock attenuating material (wood blocks between the support structure and slab used in previous test) and the use of more flexible support in the Slab Response Test Series 2. A repetition of that round (Round 11, Figure 42) -- using the same weight at the same scaled distance as in Slab Response Test Series 2 (Figure 25) produced incipient failure in the slab (still considerably more damage than in the original test).

Spalling was quite extensive on both sides of the strengthened slabs. However, in all cases where reinforcement did not fail the spalling did not penetrate beyond the depth of reinforcement.

Rounds 13-16 were tested to investigate the storage capacity of the anticipated 1/3 scale modified C-13 test. All these slabs (which represented C-13 cubicle wall and were tested under conditions planned for C-13) sustained damage of less than incipient failure; this points to the fact that the cubicle should withstand the 1,620 lbs. full-scale equivalent charge without failing (Figures 44-47).

Conclusion

Further strengthening of slabs using a high degree of

flexural reinforcement in combination with shear reinforcement significantly increased its resistance to blast loads. Proper detailing of reinforcing ties (diagonal continuous shear reinforcement) contributed significantly to blast resistance properties of a slab.

An increased amount and proper placement of flexural and shear reinforcement not only increased slab capacity but also reduced formation of high speed translational fragments.

Use of attenuating blocks between the slab and support structure (wood or concrete) as well as a flexible support structure tends to reduce the damage to a slab subjected to blast loads and produce somewhat misleading explosive capacities of the slabs in these tests. Therefore, future slab tests will utilize a more solid structure and will eliminate the use of shock absorbing blocks.

Based on results in Rounds 13-16, it is believed that the modified C-13 cubicle will withstand a load of 1,600 lbs. HE equivalent.

Equivalent Charge Test 1

Purpose of this test series was to determine the fragment velocities and to assess the damage to the slab specimens under various load conditions in a simulated cubicle type structures. In addition, impulse measurements were made by the use of plug gages of known mass.

Since the evaluation of velocity data (of wall fragments as well as aluminum plugs) was not completed the discussion of the test results will pertain only to damage sustained by the slab specimens.

Table 12 shows nine of the 12 slabs tested disintegrated while shear failure of the concrete occurred in two slabs (Rounds 4/2 and 10/2, Figures 51 and 57) and only one sustained heavy damage (Round 12/2, Figure 59). In those tests where the charges were located at scaled distances equal to or less than 0.8 from the slabs, both the concrete and the reinforcing steel disintegrated except Slab 12/2 which was 13 inches thick (equivalent to three feet, three inches in prototype construction). The major portion of the concrete of the slabs after these tests was in the form of rubble and was dispersed from the immediate area of testing.

Except for Round 10/2 (Figure 57), in those tests where the scaled distance was greater than 0.8 but equal to or less than 1.25, the concrete rubble remained within the immediate area. Round 10/2 exhibited a shear failure of the concrete rather than disintegration. This can be attributed to the reduced impulse loads resulting from greater separation of the side walls in this test ($Z_B/Z_A = 1.0$). Slab 4/2 failed due to excessive shear stresses in the concrete (Figure 51). As in the case of Round 10/2, the magnitude of the applied loads was not large enough to produce concrete disintegration. It is evident from the results of Rounds 4/2 and 10/2 that the flexural reinforcement did not fail, and if shear reinforcement were provided in both specimens those rounds might have been capable of sustaining the applied blast loads.

1/10 Scale Slab Tests

Introduction

A series of 1/10 scale model reinforced-concrete slab tests were performed at Picatinny Arsenal's test facility to investigate the feasibility of slab testing at this scale.

In this test series, scaled-down HE charges were detonated adjacent to scale model reinforced concrete slabs and the response of these slabs to the blast loading was measured in terms of slab damage or velocity of concrete fragments. The results were then analyzed for comparison with results of the corresponding 1/3 scale model slab tests performed at the U. S. Naval Ordnance Test Station (NOTS), China Lake, California facility.

A total of 19 tests were performed and the results indicated a strong similarity between 1/10 and 1/3 scales. It was concluded that this method of model testing is feasible where qualitative or semi-quantitive results are required. For more detailed quantitative testing a refinement of present model test techniques will be required.

This test series was conducted to establish the validity of 1/10 scaling to formulate a method by which results from small scale model tests can be used to predict the response of a full-scale structure to explosion effects.

A series of 19 one-tenth scale slabs were performed during the year at the test area of Picatinny Arsenal. Details of this test series are in Reference 6.

Test Set-Up

All tests were performed in a vertical position utilizing the steel tunnel technique similar to that used at NOTS. One high-speed camera (shadowgraph method) measured the velocity of slab fragments traveling across the steel plate tunnel transverse to the axis of the tunnel. Another high-speed camera (backboard technique) measured the fragment velocity moving past a wooden backboard which was marked with a linear distance scale composed of vertical stripes equally spaced on a vertical board.

The third high-speed camera facing the rear of the slab (acceptor face) recorded failure of its rear face.

In this test series, spherical Composition B donor charges were used whose weights were scaled-down versions of the charges used in 1/3 scale tests. The scaling factor equaled 1/1,000 of the prototype charge or 27/1,000 of the 1/3 scale equivalents.

The test slabs were scaled down to 1/10 size of the prototype (full-scale) slabs. All linear dimensions were divided by a factor of 1/10. The reinforcing steel area per linear foot of slab was divided by a factor of 1/10 while the percentage of reinforcing steel per concrete area was constant for model and prototype slabs.

The test slabs were supported in a vertical position on the tunnel plate. The steel test tunnel constructed at Picatinny Arsenal is made up of steel wall sections embedded in the earth. The tunnel is basically a scaled-down version of the steel tunnel used for the 1/3 scale test slab at NOTS except for the adjustment provisions to be used for 1/8 and 1/5 scale slabs. This is done by placing heavy armor plates in front of the tunnel opening for 1/8 scale with larger opening and for 1/10 scale slabs with smaller opening. For the 1/5 scale slab tests, the space in the wall is utilized for the unsupported span with the tunnel wall used as the slab support.

Two one-inch-thick steel plates placed perpendicular to the test slab served to simulate the cubicle arrangement to account for the effects of blast wave reflections from adjacent surfaces. The instrumentation consisted of motion and still picture cameras described previously. The deflections at various points on the slabs were taken by manual measurements.

Discussion

This discussion of test slab results is oriented towards establishing the validity of scaling by comparing the 1/10 scale test results with the corresponding 1/3 scale slab tests performed some time ago at the NOTS facility.

Table 14 summarizes the results of these tests. The 1/10 scale results are listed parallel to the results of the corresponding 1/3 scale tests. In general, the major conclusion from this test series was; the damage to the test slabs was similar for both the 1/10 and 1/3 scale tests. In most cases, the extent of the damage was close enough to be within the same damage classification. However, in the cases where there was a difference, the variation between the two scales was usually in the direction of greater damage to the 1/3 scale. (See Round 6 vs. Round 14-1 in Table 14 and Figure 60). A quantitative evaluation of the slab damage in relation to the parameters of kinetic energy, stress and movement in the slab will be given in a future report comparing the different scale slab tests.

Another conclusion reached from this series was that the testing techniques used are generally satisfactory for attaining the objectives of the test series. However, an improvement is needed in the method of restraining the slabs to better define the effects of the slab end conditions on the test results. It is also felt that the results to date are sufficiently consistent to justify confidence in 1/10 scale slab testing when semi-quantitative results are required. However, additional testing will be required at this scale to further define the different parameters in their relationship to the scaling factors. A detailed discussion and analysis of the 1/10 scale test results is in Reference 6.

TABLE 14

SCALING INVESTIGATION, ONE-TENTH SCALE SLAB TEST SERIES

Type Slab	Charge (1)		Full Scale Equiv	Avg Fragment Velocity		Test Results	Corresponding One-Third Scale Slab Test		Fig. No.
	W	Z_A		Shadow-graph	Back-board		Type Slab	Results	
Std. #1	0.25	0.45	250	-	-	Complete destruction, fragments propelled 4 ft.	Std. #1	Complete destruction.	
Std. #1	0.25	0.45	250	-	116	Complete destruction, fragments propelled 3 ft.	Std. #1	Complete destruction.	
Std. #1	0125	0145	250	-	105	Complete destruction, fragments propelled 1'	Std. #1	Complete destruction.	
Std. #1	0.25	0.45	250	-	148	Complete destruction, fragments propelled 7 ft.	Std. #1	Complete destruction.	
Std. #1	0.27	0.45	270	-	134	Rounds 1-5 were callibration shots. Complete destruction, fragments propelled 10 ft.	Std. #1	Complete destruction.	
Std. #2	0.26	1.5	260	-	-	Reinforcement intact; few major cracks, slight spalling	Std. #3	Reinforcement intact. Center portion broken and thrown through tunnel opening.	60
Str. #1	0.26	0.5	260	-	-	Reinforcement intact; major crack in the middle. Spalling.	Str. #4	No reinforcement failure. Spalling on both sides.	61
Str. #1	0.53	0.5	530	83	160	Center part reduced to rubble. Reinforcement heavily bent but not broken.	Str. #4	Complete destruction. All concrete stripped at center. Slab folded 180°.	62
Str. #2	0.53	0.5	530	100	81	Failure of negative reinforcement and spalling (donor panel). No reinforcement failure, but heavy spalling and deflection (acceptor panel).	Str. #6	Slab folded in two. Tension reinforcement failed. Concrete crushed at center.	63
Str. #2	0.53	0.8	530	-	-	No reinforcement failure. Both faces spalled at center.	Str. #6	Slab remained intact. Slight spalling acceptor face.	64
Str. #3	0.83	0.5	810	-	-	No reinforcement failure. Slight cracking.	Str. #8	No reinforcement failure. Heavy spalling.	65
Str. #3	0.81	0.4(2)	810	111	122	Deep spalling-acceptor face. Deflections ¼"	Str. #8	Deep spalling-acceptor face. Slight deflections.	66
Str. #4	0.81	0.5	810	68	74	No reinforcement failure. Spalling at center donor face. Deep spalling between supports - acceptor face.	Str. #14	No reinforcement failure. Spalling of both donor and acceptor faces.	67
Str. #4	0.79	0.4	790	-	150	No reinforcement failure. Deep spalling at center (donor face) and at supports (acceptor face).	-	No test.	
Comp. #1	0.53	0.5	530	-	-	No reinforcement failure. Some cracking (acceptor panel). Max. deflection ¼" (donor panel)	Comp. #2	No reinforcement failure. Minor cracks - acceptor panel. Deflection 3/4" (acceptor panel) 2½" (donor panel)	68
Comp. #2	0.81	0.5	810	-	-	No reinforcement failure. Light cracking acceptor panel. cracking and spalling donor panel.	-	No test.	
Comp. #2	0.81	0.5(2)	810	112	-	No reinforcement failure. Cracking and spalling-donor and acceptor panels.	Comp. #5	No reinforcement failure. Spalling and cracking-donor panel. Spalling-acceptor panel.	69
Comp. #3	0.8	0.4(2)	800	-	-	No reinforcement failure. Light cracking acceptor panel. Heavy spalling, partially broken (deflection 3/4") donor panel.	Comp. #6	No reinforcement failure. Light cracking - acceptor panel. Cracking and heavy spalling-donor panel.	70
Comp. #3	1.08	0.5	1, 080	-	-	No reinforcement failure. Light cracking, spalling - donor panel. No damage - acceptor panel.	Comp. #6	No reinforcement failure. Hairline cracks-acceptor panel. Heavy cracking, deflections-donor panel.	71

(1) Glossary: W - charge weight in lbs.
Z_A - scaled distance ft/lbs$^{1/3}$

(2) Simulated back wall condition in a cubicle

Std. - Standard
Str. - Strengthened
Comp. - Composite

TEST PLAN FOR FUTURE MODEL SCALE SLAB TESTS SERIES TO BE PERFORMED IN 1966

1/3 Scale Slab Test Series

The Slab Response Test Series 4 is divided into three phases A, B and C.

The objectives of this series are to:

1. Obtain design data which will relate slab-to-thickness ratio in terms of structural response. (Phases A and B)

2. Evaluate the addition of cut wire and nylon fiber to concrete in increasing its tension capacity. (Phase C)

3. Evaluate the method of bolting test specimens to the support structure to simulate fully restraining test specimens. (Phase A)

4. Determine explosive resisting capacities of panels which can move inward (unrestrained) in comparison to those panels which are restrained from moving. (Phase A)

5. Evaluate the additional blast energy absorbed by the use of wood or concrete support blocks in the test set-up. (Phase A)

6. Evaluate the lower strength concrete (f_c' 2,500 to 3,000 psi) in comparison to higher strength concrete ($f_c' = 6,000$ psi). (Phase B)

This series is an extension of previous tests which were performed to accumulate qualitative and quantitative data on the structural response of concrete. Slabs to be used in Phase A are modified versions of those used in Slab Response Test Series 3 which provide for bolting to the support structure.

Instrumentation

Camera Coverage -- Documentary and high-speed motion pictures and still photography will be utilized. The still photography will record construction phases of the test as well as pre-shot arrangement and post-shot results. The motion pictures will be used to determine failure characteristics of the test specimens including fragment velocities, sizes and distribution resulting from break-up of any portion of the test specimen.

Three basic high-speed motion picture techniques will be used:

Shadowgraph Method -- to determine fragment (both concrete and impulse plugs) masses and velocities by means of high-speed camera (about 7,000 frames per second) and a searchlight located at opposite ends of the tunnel in the support structure.

Backboard Viewing Method -- where the high-speed camera (400-600 frames per second) faces the backboard and the line-of-sight of the camera is perpendicular to the path of the fragments from the test specimens. This method is used to determine the masses and velocities of fragments (both concrete and impulse plugs).

Rear View Camera -- records the damage sustained by the acceptor surface of the test specimen from the beginning to the end of the tests (about 2,000 frames per second).

Deflection Gages -- One linear transducer will be used to measure the deflection at the center of each plain slab of Section B of the test series. Gages will not be used for the composite slab tests.

Procedure -- All but one test specimens are reinforced concrete slabs (plain, composite or with added fibrous materials) varying in thickness from 4 to 12 inches and length from 4 feet 8 inches to 9 feet, 4 inches. The non-concrete panel is constructed of structural steel, (7 feet long, 4 feet high and 6 inches thick) and will be used to evaluate impulse loads in a C-13 cubicle in repetitive tests. A summary of the

individual phases of tests anticipated in this series is in Table 15. The support structure will be modified to accommodate the slab bolting technique. In those tests where the cubicle arrangements are used structural steel plates will be utilized as side walls. The explosive charges to be used in this series (20-100 lbs.) will consist of bare cylindrical charges of Compsoition B primed with Composition C-4 and detonated with Engineer's Special Blasting Caps.

Test Plan for 1/8 and 1/5 Scale Slab Tests

These two test series consisting of about 20 rounds each are part of a model test program designed to provide qualitative, semi-quantitative and quantitative information pertaining to the validity of scaling.

These test series will serve to establish the usefulness of performing 1/8 and 1/5 scale tests, and in addition, will provide supplementary information pertaining to structure response. The tests will be carried to a point where structural damage, fragment velocities and masses can be related to similar test results from 1/3 scale model tests and possibly full-scale tests.

Objective

The purpose of these test series is to establish the validity of 1/8 and 1/5 scaling and to establish a method by which results of 1/8 and 1/5 scale tests can be used to predict the behavior of full-scale structures in explosive storage and manufacturing facilities.

Test Set-Up

Testing will be performed at Picatinny Arsenal facility using the steel tunnel previously described. The tunnel arrangement is used to support the test specimen thereby simulating the single adjacent reflecting surface (ground surface). Both motion and still cameras will record the results similar to the 1/3 Scale Slab Test.

TABLE 15

PRELIMINARY TESTING PLAN FOR SLAB RESPONSE TEST SERIES No. 4

SERIES 4a	SLAB PROPERTIES					TEST ARRANGEMENT				
Name of Slab	Dimensions (1)		Longitude Reinforcement %			Charge Properties			Cubicle	Remarks
	Span	Thickness (In.)	Donor Surface	Acceptor Surface	Stirrups	W lbs.	R In.	Z_A ft/lbs$^{1/3}$	Type Z_B/Z_A	
Str. No. 11	2	4	0.65	0.65	0.15	20	33	1.0	None	
Str. No. 11	2	4	0.65	0.65	0.15	20	33	1.0	None	
Str. No. 11	2	4	0.65	0.65	0.15	20	33	1.0	0.89	
Str. No. 14	2	6	2.7	2.7	1.2	30	18.5	0.5	1.0	
Comp. No. 9	2	4(6)4	0.65	0.65	0.15	30	18.5	0.5	None	
Str. No. 12	2	4	0.65	0.65	0.30	20	41.0	1.25	None	Use of loop shear reinf.
Comp. No. 9	2	4(6)4	0.65	0.65	0.15	30	29.5	0.8	None	
Comp. No. 10	2	4(12)4	2.7	2.7	1.2	60 (2)	0.5	0.5	None	
SERIES 4b										
Comp. No. 9	2	4(6)4	0.65	0.65	0.15	30	18.5	0.5	None	
Comp. No. 9	2	4(6)4	0.65	0.65	0.15	30	29.5	0.5	None	
Str. No. 13a	2	4	2.7	2.7	1.2	20	24.0	0.75	1.0	
Str. No. 13a	2	4	2.7	2.7	1.2	30	18.5	0.5	1.0	
Str. No. 14a	2	6	2.7	2.7	1.2	30	18.5	0.5	1.0	
Str. No. 14a	2	6	2.7	2.7	1.2	30	To be decided later			
Str. No. 16	2	12	2.7	2.7	1.2	80	15.5	0.3	1.0	
Str. No. 16	2	12	2.7	2.7	1.2	80	To be decided later			
Str. No. 17	3	4	2.7	2.7	1.2	20	29.0	0.9	1.0	
Str. No. 17	3	4	2.7	2.7	1.2	20	To be decided later			
Str. No. 18	3	6	2.7	2.7	1.2	30	24.0	0.65	1.0	
Str. No. 18	3	6	2.7	2.7	1.2	30	To be decided later			
Str. No. 19	3	12	2.7	2.7	1.2	80	16.0	0.35	1.0	
Str. No. 19	3	12	2.7	2.7	1.2	100	To be decided later			
Str. No. 11a	2	4	0.65	0.65	0.65	20	33.0	1.0	None	
Str. No. 11a	2	4	0.65	0.65	0.65	20	33.0	1.0	0.89	
Str. No. 13b	2	4	2.7	2.7	1.2	20	24.0	0.75	None	Use of low strength concrete
Str. No. 13b	2	4	2.7	2.7	1.2	20	24.0	0.76	1.0	Use of low strength concrete
Steel Panel No. 1	2	4	-	-	-	60 (2)	19.5	0.42	0.87	
Steel Panel No. 1	2	4	-	-	-	60 (2)	19.5	0.38	1.15	Side wall arrangement
SERIES 4c										
Str. No. 11b	2	4	0.65	0.65	0.15	20	33.0	1.0	None	Use of cut steel wire
Str. No. 11b	2	4	0.65	0.65	0.15	20	33.0	1.0	0.89	Use of cut steel wire
Str. No. 11c	2	4	0.65	0.65	0.15	20	33.0	1.0	None	Use of nylon fiber
Str. No. 11c	2	4	0.65	0.65	0.15	20	33.0	1.0	0.89	Use of nylon fiber
Str. No. 13c	2	4	2.7	2.7	1.2	20	24.0	0.75	None	Use of cut steel wire
Str. No. 13c	2	4	2.7	2.7	1.2	20	24.0	0.75	1.0	Use of cut steel wire
Str. No. 13d	2	4	2.7	2.7	1.2	20	24.0	0.75	None	Use of nylon fiber
Str. No. 13d	2	4	2.7	2.7	1.2	20	24.0	0.75	1.0	Use of nylon fiber

(1) Numbers in parenthesis indicates thickness of sandfill.

(2) 6 x 10 lb. charges to be used.

Str. - Strengthened concrete

Comp. - Composite

Twenty rounds will be used in each of the two series to test 11 different slab designs (both plain and composite). A tentative test program for both series is shown in Table 16, which also includes data for comparable test slabs in the other scaled test series.

TABLE 16

COMPARISON OF TEST SPECIMENS FOR VARIOUS SCALED TEST SERIES

Full Scale Slabs				One-Third Scale Slab				One-Fifth Scale Slab				One-Eighth Scale Slab				One-Tenth Scale Slab				Remarks
Slab No.	W	Z_A	Cubicle	Slab No.	W	Z_A	Cubicle	Slab No.	W	Z_A	Cubicle	Slab No.	W	Z_A	Cubicle	Slab No.	W	Z_A	Cubicle	
Std. 2	100	0.46	-	Std. 4	3-3/4	0.46	-	Std. 1	.80	0.46	-	Std. 1	0.20	0.46	-					Horizontal Test - No Blocks
Str. 1	500(1)	1.00	-	Str. 11	18-1/2(1)	1.00	-	Str. 1	4.00(1)	1.00	-	Str. 1	0.98(1)	1.00	-					Horizontal Test - No Blocks
Str. 1	500(1)	0.50	-	Str. 11	18-1/2(1)	0.50	-	Str. 1	4.00(1)	0.50	-	Str. 1	0.98(1)	0.50	-					Horizontal Test - No Blocks
Comp. 1	750(2)	0.50	-	Comp. 3	27-3/4(2)	0.50	-	Comp. 1	6.00(2)	0.50	-	Comp. 1	1.47(2)	0.50	-					Horizontal Test - No Blocks
Comp. 1	750(2)	(3)	-	Comp. 3	27-3/4(2)	(3)	-	Comp. 1	6.00(2)	(3)	-	Comp. 1	1.47(2)	(3)	-					
				Std. 1	10	0.46	-									Std. 1	0.27	0.46	-	
				Std. 1	10	0.47	-									Std. 1	0.27	0.47	-	
				Std. 1	10	0.50	-									Std. 1	0.27	0.50	-	
				Std. 1	10	0.50	-									Std. 1	0.27	0.50	-	
				Std. 1	10	0.51	-									Std. 1	0.27	0.51	-	
				Std. 3	10	1.50	-	Std. 2	2.16	1.50	-	Std. 2	0.53	1.50	-	Std. 2	0.27	1.50	-	
				Str. 4	10	0.50	-	Str. 2	2.16	0.50	-	Str. 2	0.53	0.50	-	Str. 1	0.27	0.50	-	
				Str. 4	20	0.50	-	Str. 2	4.32	0.50	-	Str. 2	1.06	0.50	-	Str. 1	0.54	0.50	-	
				Str. 6	20	0.50	-	Str. 3	4.32	0.50	-	Str. 3	1.06	0.50	-	Str. 2	0.54	0.50	-	
				Str. 10	20	0.80	-	Str. 3	4.32	0.80	-	Str. 3	1.06	0.80	-	Str. 2	0.54	0.80	-	
				Str. 8	30	0.50	-	Str. 4	6.48	0.50	-	Str. 4	1.59	0.50	-	Str. 3	0.81	0.50	-	
				Str. 8	30(1)	0.40	(4)	Str. 4	6.48(1)	0.40	(4)	Str. 4	1.59(1)	0.40	(4)	Str. 3	0.81	0.40	(4)	Concrete (Cast) Block
				Str. 14	30	0.50	(5)	Str. 5	6.48	0.50	(5)	Str. 5	1.59	0.50	(5)	Str. 4	0.81	0.50	(5)	
				Str. 14	(3)	(3)	(3)	Str. 5	(3)	(3)	(3)	Str. 5	(3)	(3)	(3)	Str. 4	(3)	(3)	(3)	
				Comp. 2	20	0.50	-	Comp. 2	4.32	0.50	-	Comp. 2	1.06	0.50	-	Comp. 1	0.57	0.50	-	
				Comp. 2	-	-	-	Comp. 2	(3)	(3)	(3)	Comp. 2	(3)	(3)	(3)	Comp. 1	(3)	(3)	(3)	
				Comp. 5	-	-	-	Comp. 3	6.48	0.50	-	Comp. 3	1.59	0.50	-	Comp. 2	0.81	0.50	-	
				Comp. 5	30	0.50	(5)	Comp. 3	6.48	0.50	(5)	Comp. 3	1.59	0.50	(5)	Comp. 2	0.81	0.50	(5)	
				Comp. 6	30(1)	0.40	(4)	Comp. 4	6.48(1)	0.40	(4)	Comp. 4	1.59(1)	0.40	(4)	Comp. 3	0.81	0.40	(4)	
				Comp. 6	40(1)	0.50	-	Comp. 4	8.64(1)	0.50	-	Comp. 4	2.12(1)	0.50	-	Comp. 3	1.08	0.50	-	

(1) Double charge.
(2) Triple charge.
(3) Properties to be selected later.
(4) Back Wall - Z_B/Z_A = 1.32
(5) Back Wall - Z_B/Z_A = 1.00

NOTES:
1. All tests to be performed vertically except as noted.
2. All tests to be performed using wood blocks except as noted.

SECTION 2

SCALED BAY TEST SERIES

Summary

The purpose of these tests was to:

1. Design a manufacturing bay to withstand 2,000 lbs. of HE.

2. Evaluate its explosive capacity.

3. Establish scaling factors that will relate the test results of a given scale model bay to results of a full-scale structure.

The full-scale bay was 40 feet long, 20 feet deep and 10 feet high, constructed of reinforced concrete, comprising a floor slab, back wall and two side walls. Each wall was of the sandwich type and had an overall thickness of eight feet (two feet concrete, four feet sand and two feet concrete). The dimensions of individual scale models, the diameter of main reinforcing bars, and charge dimensions were scaled linearly.

The explosives were spherical Composition B charges. The 1/10 and 1/8 scale model tests were performed at the Picatinny Arsenal Test Facility. The 1/5 and 1/3 scale model tests were performed at the A. D. Little Test Facility in Hinsdale, New Hampshire. Three tests were performed on each 1/10, 1/5 and 1/3 scale model and four tests on the 1/8 scale model (a total of 13 tests).

In the first test series, all model structures withstood the 2,000 lbs. equivalent charge practically intact except for minor cracks in the back wall. In the second test series (with 3,000 lbs. equivalent charge weight), the model structures suffered only minor damage. The donor panels suffered heavy damage (through less than incipient failure) but the acceptor panels showed only minor cracks. In the third test series (with 5,000 lbs. equivalent charge), both the donor and acceptor panels suffered heavy damage in the 1/10 and 1/5 scale models and somewhat less damage of acceptor panels in the 1/3 and 1/8

scale models. In the test of the 1/3 scale model -- since explosive limits provented using more than a 3,000-lb. equivalent -- the charge was moved closer to the wall in an effort to simulate an impulse equivalent to that produced by 5,000 lbs. of explosives. The validity of scaling was shown clearly in all tests with comparabl equivalent charge weight.

All tests were documented by high-speed and still photography. Post-shot measurements of wall deflections were taken for each round. For 1/5 and 1/3 scale structures, instrumentation consisted of strain and deflection gages. Both types of gages were used to determine the mechanism of dynamic wall failure under explosive loading conditions. The deflection gages were used to record the time history of the deflections of the back walls. A complete report covering detailed analysis of the design of the structure and the results of the 1/10 scale bay test results is in Reference 7.

Introduction

At the request of the Armed Services Explosives Safety Board (ASESB), a program was initiated to design a bay structure of certain internal dimensions which would withstand the blast effects of an explosion of 2,000 lbs. of HE (Composition B). Included in this study was the establishment of model factors which would indicate the feasibility of using model scale structures in explosive storage and manufacturing problems and the degree to which scaling may be used in future tests. Therefore, this program used model scales of 1/10, 1/8, 1/5 and 1/3 scales of the prototype structures. A full-scale prototype structure will be tested in 1966.

Both the model factors and the explosive storage capabilities established from these tests will be applied to this specific structural configuration and therefore may be considered quantitative

Test Set-Up

Each test set-up comprised three components:

- Donor charges
- Instrumentation (gages, photographic coverage)
- Test structure

Donor Charges

Charges utilized in all tests were bare spherical Composition B charges. Although the size and weight of charges varied from round-to-round, their geometric center (whether for individual charges or in cluster) always was in the center of the bay -- midway between the side walls, half-way from the back wall and the floor. In those rounds where cluster arrangement was employed, the individual charges were placed in a plane parallel to the back wall. Initiation of the charges was accomplished by means of Engineer's Special Blasting Caps placed in a radial hole drilled in the charge. Physical properties of the donor charges for the various structures is in Table 17.

Instrumentation

Photographic Coverage -- Two types of photographic coverage were used: still photography and high-speed motion photography. The still photography recorded both pre-shot and post-shot test arrangements and results. The motion pictures were used primarily to determine the damage characteristics of the test structure including secondary fragment velocities and fragment distribution. Two basic motion picture arrangements were employed:

Backboard method
Rear face (wall) viewing method

The primary purpose of the first method was to determine fragment velocities from the back wall if any were formed and the second method recorded the manner in which the test structure was damaged. The first motion picture technique incorporated the use of a 16mm camera and a wooden backboard. The camera faced the backboard and the line-of-sight of the equipment was perpendicular to the path of fragments from the test structure. Both the camera and the center line of the backboard were located at such a distance that the dust formed near the test structure did not obscure the movement of the fragments. The second motion picture technique or the rear-face viewing method recorded a rear view of the damage sustained by the rear surface of the center wall from the beginning to the end of the test. Flash shields were utilized to restrain the gases, smoke and dust formed by the explosion.

TABLE 17

PHYSICAL PROPERTIES OF EXPLOSIVES

Structure	Round No.	Type of Charge	Unit Weight (lbs.)	Quantity	Total Weight (lbs.)	Distance to Back Wall (ft.)	Scaled Distance ft./lbs.$^{1/3}$	Equiv. Full Scale Weight (lbs.)
1/10 Scale	1	Single	2.00	1	2.00	1.0	0.795	2000
	2	Cluster	1.08	3	3.24	1.0	0.675	3240
	3	Cluster	0.81 1.00	4 1	3.24 1.00 } 4.24	1.0	0.620	4240
1/8 Scale	1	Single	4	1	4	1.25	0.790	2048
	2	Single	6	1	6	1.25	0.690	3072
	3	Single	10	1	10	1.25	0.580	5120
	4	Cluster	10 5	1 1	10 5 } 15	1.25	0.506	7680
1/5 Scale	1	Single	16	1	16	1.98	0.785	2000
	2	Single	24	1	24	1.98	0.688	3000
	3	Cluster	16 24	1 1	16 24 } 40	1.98	0.580	5000
1/3 Scale	1	Single	75	1	75	3.27	0.775	2025
	2	Single	112	1	112	3.27	0.680	3024
	3	Single	112	1	112	2.56	0.530	3024

Gages -- Gages were used only in the 1/3 and 1/5 scale tests performed at the A. D. Little test facility. Two kinds of gages were used: strain gages and deflection gages. The strain gages were cemented directly to reinforcing bars at critical points within the structures before the concrete was poured. The gages were used to determine, if possible, the mechanism of dynamic wall failure under explosive loading conditions. The deflection gages were linear displacement tranducers which operate on the principle of change in inductance in the coils of a linear differential transformer with changes in position of the core. The transformer units were mounted on a concrete block isolated from the bay while the probe was attached to the bay walls by rods. The output of the transducer was recorded as a function of time so that a complete picture of the wall movement vs. time was obtained (Figure 72). Description of the instrumentation in this program is in Reference 8.

Description of the Structure

The prototype structure is so designed as to represent adjoining cells that would exist in an actual explosive manufacturing facility (Figure 73). All structural components are constructed exclusively of reinforced concrete and comprise chiefly floor slab, back wall and two side walls; the front and top of the structure remain open to the atmosphere. The overall dimensions of the prototype structure are: 40 feet in length, 20 feet in depth and 10 feet in height. The scaled model bay dimensions were determined by dividing the prototype by the scaling factors. Actual dimensions of the structures used in various scale models are in Table 18. A composite (sandwich) type wall construction featuring two reinforced-concrete panels separated by a sand fill is utilized in the structure, each wall having an overall eight foot thickness (Figures 73 and 74). The cross-section of the prototype structure for all walls is: two-foot-thick donor panel, four-foot-thick sand fill and two-foot-thick acceptor panel. At the intersection of the side wall and the back wall, a sand-filled cylindrical cavity extends to the pedestal.

At the exterior of the bases of all three walls are reinforced concrete haunches. These haunches are tied to the remainder of the structure by reinforcing steel. Separating each concrete panel of each wall at the base are reinforced concrete pedestals.

TABLE 18 - MAIN DIMENSIONS OF STRUCTURES

Structure	Cubicle (Interior)			Walls			Floor Slab Thickness		Diameter of Main Reinforcing Bars (in.)
	Length (ft.)	Depth (ft.)	Height (ft.)	Donor Panel (in.)	Sand Fill (in.)	Acceptor Panel (in.)	Peripheral Slab (in.)	Central Slab (in.)	
1/10 Scale	4	2	1	2 7/16	3 3/4	2 7/16	2 7/16	1 3/16	0.12
1/8 Scale	5	2.5	1.25	3	6	3	3	1 1/2	0.13
1/5 Scale	8	4	2	4 13/16	9 5/8	4 13/16	4 13/16	2 3/16	0.22
1/3 Scale	13.3	6.7	1.3	8	16	8	8	4	3/8
Full Scale Prototype	40	20	10	24	48	24	24	12	1 1/8

These pedestals are connected by reinforcing steel both to the concrete panels and to the floor slab thereby forming a "tie beam". Adjacent to the walls is the peripherial floor slab which has a thickness of two feet (prototype) and which surrounds the "central floor slab" the latter having a one foot thickness. The transition between the two thicknesses is accomplished by means of an intermediate taper.

Model Scale Test Structures

The geometrical scaling method was utilized for determining the size of the test specimen (Reference 1). Both the dimensions and the reinforcement of the test structure were scaled in accordance with the size of the model. The dimensions of the structure, as well as the sizes and the spacing of the reinforcing bars, were varied in direct proportion to the scaling factor of the model: the cross-section area of the reinforcement was scaled as a function of the square of the scaling factor. If (as was inevitable in certain instances) the exact scale bar sizes and spacing could not be provided in the model due to the non-availability of the particular bar or wire size required, the sizes and spacing were adjusted to furnish the proper scaling of the reinforcement area -- thereby maintaining the correct scaled strength of the structure.

Basis for Design

Sandwich type wall construction of the proportions incorporated in the prototype affords efficient, inexpensive absorption of blast energy by reason of the large volume of the low-cost sand in the cavity between the donor and the acceptor panels (Figure 75). Although the sand adds mass to the structure, its primary purpose is to assist the concrete panels in restraining a portion of the blast impulse. This restraint results from the energy-absorbing capacity of sand due to the force required for compacting the sand -- for displacing the individual particles toward the adjacent interstices. A pedestal or tie beam is provided at the base of the wall to tie the donor panel to the acceptor panel at the base and at the sides thereby ensuring a completely monolithic wall.

A haunch or curb, which is non-integral with the walls but integral with the floor and pedestal slab, was included at the base of each wall of the 1/10 and 1/8 scale models to prevent a build-up of the reflected pressure due to the blast. Inserted between the vertical face of the haunch and the panel in the 1/10 scale model only was a resilient filler, the purpose of which was to cushion the load to the pedestal. The haunches of the 1/5 and 1/3 scale models were integral with the walls.

At the base of each wall panel, a lip provided anchorage for the vertical reinforcing bars in such a manner that both of the panels acted monolithically with the floor slab. The end panel closures, by reason of their shear action, also provided a certain amount of supplementary strength to the walls. A cylindrical cavity was provided at the back wall to prevent concentrations of stress at that area.

Extending a predetermined distance from each wall was the peripheral floor slab having a thickness to develop the full strength of the wall. The thickness of the central portion floor slab was 50% that of peripheral slab. The purpose of the thinner section was to reduce construction costs and to have the applied blast loads to be borne primarily by the underlying soil instead of the walls.

In addition to the main horizontal and vertical reinforcement, all three walls contained diagonal shear reinforcement situated in the upper portion of the panel where shearing stresses were greatest. Details of reinforcement during construction of the 1/10 and 1/3 scale bays are in Figure 76.

Discussion of Test Structures

General -- The discussion of this bay test series concentrates on the first two rounds in each model bay with 2,000 and 3,000 lbs. full-scale equivalent while only a limited comparison can be made for Round 3 (5,000 lbs. full-scale equivalent) because of different set-ups used in this round. Also the emphasis is placed on discussing the back wall of the bay since it is the critical section of the structure. A summary of test results is in Table 19. The maximum deflections of the back wall in all models is in Table 20. Figure 77 shows the test set-up of each of the scaled bays before the initial test.

Round 1 -- In general, the four structures -- 1/10, 1/8, 1/5 and 1/3 scale -- sustained about the same degree of damage with slightly

TABLE 19

SUMMARY OF SCALE MODEL BAY TEST RESULTS

Structure	Rd.	CHARGE PROPERTIES				Fig. No.	SUMMARY OF DAMAGE	
		Type	Wt. lbs.	Scaled Distance from BW	Eqv. Full Scale Wt. lbs.		Side Walls	Back Wall
1/10 Scale	1	Single	2.0	0.8	2,000	78	Scattered cracks	Light cracking
	2	Cluster	3.24	0.675	3,240	80	Light cracking	Heavy cracking, some spalling
	3	Cluster	4.25	0.620	4,250	82	Light cracking, spalling donor panels	Partial destruction **
1/8 Scale	1	Single	4.0	0.79	2,000	78	Few scattered cracks	Light cracking (donor panel)
	2	Single	6.0	0.69	3,000	80	Light cracking, spalling (donor panel)	Light cracking, spalling (donor panel)
	3	Single	10.0	0.58	5,000	82	Medium damage **	Medium damage
	4	Cluster	15.0	0.50	7,500	84	Partial destruction ** (donor panels) Medium damage (acceptor panels)	Partial destruction, collapse of donor and acceptor panels
1/5 Scale	1	Single	16.0	0.785	2,000	78	Light cracking & light spalling (donor panels)	Light cracking & spalling (donor panels)
	2	Single	24.0	0.688	3,000	80	Heavy cracking & spalling (donor panels)	Medium damage
	3	Cluster	40.0	0.58	5,000	82	Heavy damage **	Heavy damage (incipient failure) extensive spalling both panels
1/3 Scale	1	Single	75	0.775	2,025	78	Light cracking	Heavy cracking, light spalling (donor panel)
	2	Single	112.5	0.680	3,040	80	Heavy cracking & spalling	Heavy cracking & spalling (donor panel)
	3*	Single	112.5	0.530	3,040	82	Medium damage (donor panel)	Heavy damage (donor panel); Light cracking, no spalling (acceptor panel)

NOTES: * Limited explosive allowance prevented testing at full charge; therefore charge was moved closer to the back wall to approximate the same impulse as the third round in other models.

** Medium damage - Large cracks; local crushing and surface pitting.
Heavy damage - Slightly less than incipient failure.
Partial destruction - Panel breaks up into few large sections.

Abbreviation: BW - Back Wall

TABLE 20 - MAXIMUM DEFLECTIONS OF BACKWALL

Panel	Round	Maximum Permanent Deflection[1]				Maximum Dynamic Gage Deflection (in.)[2]	
		1/10 Scale	1/8 Scale	1/5 Scale	1/3 Scale	1/5 Scale	1/3 Scale
Donor	1	3/16	3/8	1 3/8	1 1/2(1 9/16)	-	3 3/8[4]
	2	1 5/16	11/16	3 1/8(3 1/8)	3 7/16	4 11/16	6 7/16
	3	-	1 1/2	7 1/2	-	-[3]	-[3]
Acceptor	1	0	0	1/8	1/8	-	1/4
	2	1/2	-	1/2	1/2	1 3/8	1
	3	-	1 1/4	4 3/4	2 5/8(1 1/2)	2 1/4	3 1/2

(1) All values were measured by hand except those in parentheses which are from deflection gage measurement (all hand measurements are accurate to ± 1/8 in.)

(2) Total deflection equals maximum deflection in the particular round plus permanent deflection of previous round.

(3) No gage installed.

(4) Estimated, actual deflection beyond calibration of gage.

more surface spalling of the donor surface of the donor panel in the two larger (1/5 and 1/3 scale) structures (Figure 78). This was apparently the result of the thicker concrete cover of the reinforcement in the bays constructed in the field as opposed to concrete cover of the smaller bays (1/8 and 1/10 scale) constructed in the laboratory. Also, the need for concrete patching of the surfaces of the two larger bays (1/3 and 1/5) contributed to more spalling of these bays. The major cracks in the back walls of the four models were similar. Both the horizontal and vertical reinforcements were intact in the back walls of all models.

The acceptor panels of the back walls of the two larger models showed virtually no damage while verticla cracks were formed near the centers of the 1/10 and 1/8 scale models (much smaller cracks in 1/8 scale model) (Figure 79). These cracks were formed due to the vertical settlement of the center of the back wall relative to sections of the structure where the side walls intersect the back wall. This settlement was attributed to the less compacted foundation soil of the smaller models (structures were tested on fill) than that of the two larger models. Cratering of the floor slab was relatively light for all models with slightly larger depressions occurring in the two smaller structures.

Except for the end panels which restrain the sand fill, little or no damage was sustained by the side walls. The side walls of the two larger structures suffered slightly more damage than the smaller ones. The probable reason for this was the placing of the reinforcement in the two larger models closer to the inner surface of the panels during construction.

<u>Round 2</u>

The reinforcement of the donor panel, of the back wall, failed near the center of the 1/10 scale structure (above the floor slab haunch). The reinforcement in the remaining three structures remained intact although shear planes were formed between the tension and compression reinforcement in the area where the 1/10 scale model reinforcement failed (Figure 80). The formation of a shear plane resulted in a reduction of wall strength as if the steel failed. The size of the shear plane formed in the 1/8 scale model was smaller than those of the other three bays. Shear failure of the concrete resulted in the formation of relatively large displacements of the donor panel. This in turn caused excess scabbing (spalling due to large straining of the reinforcement or displacement of the

panel). Spalling of the donor surfaces of the donor panels of the back wall was quite heavy except in the 1/8 scale model where a smaller shear plane was formed.

The vertical cracks in the acceptor panels of the back wall were quite pronounced in the two smaller (1/10 and 1/8 scale) models (Figure 81). Similar but smaller cracks were formed in the two larger bays. The vertical cracks in the 1/10 scale model extended the full height of the wall. Formation of these vertical fissures eventually caused the failure of those structures which collapsed. In all models, the craters formed in the floor slabs enlarged appreciably and penetrated the slabs and displaced the subgrade.

The side walls of all models suffered appreciably more damage than in Round 1. The walls of the two larger models, particularly the end panels, suffered more damage than the smaller (1/10 and 1/8) scale models. Here again the method of pouring the concrete -- which differs in the field from that in the laboratory -- apparently contributed to the greater damage for various scale models. As can be seen from the discussion the difference in the damage for various scale models -- although insignificant -- can be attributed primarily to secondary causes such as the method of pouring different foundations (fill vs. consolidated ground) rather than to scaling factors. In some instances, the damage was greater to smaller models; in others to the two larger models. There was no definite pattern indicating that the degree of damage increased or decreased with the size of the scale model.

<u>Round 3</u>

A comparison of various models can be done only superficially since the conditions of testing (cluster of charges, charge size limitation, etc.) were not exactly the same for all scale model bays. For the three larger models (1/8, 1/5 and 1/3 scale), the damage was comparable in that the back and side walls of the donor panel failed (Figure 82) while the acceptor panels remained undamaged (Figure 83). The back wall of the 1/10 scale bay failed due to the enlargement of the vertical cracks formed in Round 1 and the eventual failure of the horizontal reinforcement. Failure in the 1/10 scale bay model was due to the applied blast loads to the side walls which induced additional tension stresses in the back wall, which also contributed to its failure. The additional stresses induced by the

side wall loads were in excess of those normally incurred because of the complete failure of the floor slab. A portion of the side wall loads are usually transferred directly through the slab thereby relieving a large part of the loads on the back wall.

Round 4

The only structure tested in Round 4 was the 1/8 scale bay. The purpose of this test was to investigate the bay's ultimate capacity by subjecting it to 7,500 lbs. of HE. As expected, the structure failed in a similar manner as the 1/10 scale bay in Round 3 (splitting of the back wall, Figure 84). The splitting action resulted in complete collapse of both the donor and acceptor panels. It should be noted that although the back wall failed no large quantities of small fragments resulted from the failure of the structure. Both panels of the wall broke into two large sections each of which rotated about its support and transferred most of the overload momentum into the ground at the rear of the structure.

Conclusions

The validity of scaling was clearly shown in all tests with comparable equivalent charge weights.

All structures withstood the 2,000 lbs. equivalent charge practically intact.

All structures withstood the blast resulting from the 3,000 lbs. equivalent charge weight with only minor damage. The donor panels suffered heavy damage but the damage to acceptor panels was only minor.

All bays (except 1/10 scale bay) suffered less than incipient failure (acceptor panels) when subjected to a load of 5,000 lbs. equivalent charge. The 1/10 scale bay failed in the third round (with 4,250 lbs. equivalent charge) because of the center crack formation in the first round. The crack formation was attributed primarily to the soft ground under the cubicle usually not encountered in actual construction.

As designed, the structure will withstand a much heavier load than the 2,000 lb. design capacity before it reaches the incipient failure condition.

TEST PLAN FOR FULL-SCALE BAY STRUCTURE

Objective

The purpose of the full-scale bay test is to evaluate the prototype of a 20 x 40 foot explosive manufacturing bay structure designed to contain 2,000 lbs. of HE. The full-scale bay test is an extension of the model tests performed on similar structures of smaller scale.

Background and Introduction

Previous tests utilizing scale models (1/3, 1/5, 1/8 and 1/10) of the prototype test structure indicated that the bay structure would survive the blast effects of 2,000 lbs. of explosives at the center of the cell. Based on the results, the data from the full-scale structure test will be used to evaluate the scaling relationships between full-scale and scale model cubicle structures. The evaluation will be made in terms of structure response such as deflections, strains, damage pattern, type of fracture, etc.

Recent explosive situations established a need for a blast-resistant structure capable of confining explosive output of donor charge in the order of 5,000 lbs. Scale model tests of the present configuration of the bay structure indicated that this structure is capable of resisting without failure the explosive output to 5,000 lbs. of HE. This test will be used to verify the model results when applied to an actual situation.

Instrumentation

Camera coverage will be the same as the one used in the scale model bay tests.

Deflection Gages -- A total of 18 linear transducers will be used to measure deflection at various points on the walls of the structure in addition to the measurement of the movement of the base slab. The gages attached to the wall will be located at two elevations. All gages will have either a 10-inch stroke (SS-582) or 6-inch stroke (SS-580).

Peak Pressure and Impulse Gages -- Measurements will be made of pressures and impulses ranging from 40 to 0.5 psi. The number and position of the gages will be established by the test personnel.

Procedure

Test Structure -- The test structure is a full-scale prototype of the scale model structures used in the scaled bay tests described previously.

Donor Explosives -- Based on results of previous scale model tests, it is anticipated that three rounds of tests will be performed. The first round will detonate a 2,000 lbs. spherical Composition B charge located at the center of the donor cell and suspended from the wall of the structure. The second and third rounds will depend on the results of Round 1. If the results from Round 1 are similar to those in the scale model bay test, then Round 2 and 3 will use 3,000 and 5,000 lbs., respectively. (Round 3 will again depend on results of Round 2). The donor used in the second round will be spherical Composition B single charge while Round 3 will consist of a number of 50-lb. light-cased charges whose total weight will be 5,000 lbs.

Data to be Obtained from the Test

Description of post-shot damage will include size and number of cracks and their locations, measurement of wall deflection, time history of wall deflection and gage reading.

Still and motion pictures will be taken during the test.

SECTION 3

1/3 SCALE MODIFIED C-13 CUBICLE TEST PLAN

The main purpose of this scale model test is to demonstrate the use of new design and construction techniques developed in component (slab) tests for use in reinforced-concrete cubicle storage facilities. In addition, the test was designed to investigate physical wall damage by measuring the maximum and permanent wall deflections and to measure fragment velocities and masses.

The anticipated test is part of a series of 1/3 scale model tests designed to provide qualitative and semi-quantitative information on the resistance of concrete, structural steel, sand and composite dividing walls subjected to explosive output. Some component (slab) tests using walls which will be used in this test were already performed during the Slab Response Test Series 3 (Rounds 13-16).

Test Set-Up

These items will be included in the test set-up:

Test cubicle
Donor charge
Photographic coverage (still and motion pictures)
Deflection gages to record the maximum and permanent deflections

A sketch showing the Modified C-13 Cubicle is presented in Figure 85. The test structure is a 1/3 scale modified version of C-13 test cubicle used in the ASESB Dividing Wall Test Program (Reference 9). Both the inside dimensions of the cubicle and the overall thickness of its walls are scaled in accordance with those of the full-scale cubicle. All three walls of the structure are a composite type consisting of reinforced concrete and sand. The scaled heights of the walls were increased above those of the original design to allow room for the additional bridge tie supports. The composite walls consist of two layers of concrete each 6 inches thick with 8 inches of sand between them (corresponding to a prototype structure of 1 1/2 - 2 - 1 1/2 feet as opposed to 1-3-1 feet in the original C-13 structure). In addition to the conventional support (floor and back wall), the side walls also are supported by three horizontal ties near the top of the walls. The base slab, acting as the lower support for all three walls of the structure, varies in thickness from a minimum of six

inches in the center portion of the cell to a maximum of 19 inches beneath the intersection of the side and back walls.

The explosive will consist of 10-lb. cased cylindrical charges of Composition B (similar to those used in the 1/3 scale C-10 cubicle test). The charges are to be detonated simultaneously with Engineer's Special Blasting Caps and booster charges of Composition C. The charges will be positioned and mounted on a four-inch high plastic foam block.

Camera coverage will consist of still and motion picture. A total of nine high-speed (16mm) cameras will be used in three basically different positions (backboard, rearface viewing and site viewing) plus one camera for overall view of the event.

A total of 18 deflection gages will be used (10 with a 6-inch deflection range and eight with a 10-inch deflection range). Purpose of these gages is to obtain the deflection history of the cubicle walls and overall movement of the structure as a result of the explosion. The deflection gages to be used are linear displacement transducers previously described.

SECTION 4

WEAPON-TO-WEAPON PROPAGATION TESTS

Objective

Purpose of this test series was to determine the practicability of compartmenting standard igloos with sandbags for storing small nuclear warheads to prevent propagation of explosion from one compartment to another.

Introduction

A test series was performed at the request of the Defense Atomic Support Agency. Four tests using bare PBX spherical charges in cans were performed in 1964 and results are in References 3 and 10. Since the results with bare charges showed them to have extremely high sensitivity (propagation occurred even with a single 50-lb. donor charge), it was decided to test an actual weapon configuration using a test layout in the igloo similar to the initial tests but only using sandbags for compartmenting.

Major technical support and procurement of reject or simulated weapons for all these tests was provided and arranged by Picatinny Arsenal personnel. These test (as the initial ones) were performed at the U. S. Naval Ammunition Depot (NAD), Hastings, Nebraska.

Results

Tests 5-10 were performed in February 1965. The igloo compartment layout is in Figures 86 and 87. (The use of plywood supporting the sandbags was discontinued at this point).

In Test 5 donor and acceptor weapons consisted of mockup Mk45 and Mk48 weapons made from rejected metal parts placed in simulated H-815 storage containers and XM467 packing case, respectively. The donor, consisting of two Mk48 mockup weapons, was placed in Cell 4 and the charges were detonated simultaneously. The igloo was completely collapsed but the back wall was virtually undamaged. All the weapon containers were bent and caved in. However, most of the weapon acceptors were found undamaged when removed from the containers. No propagation occurred to any of the acceptors.

In Test 6 (with identical igloo layout), two Mk48 Simulators were used in place of mockups. Otherwise everything was identical with Test 5. The damage to the igloo and the weapons was about the same as in the previous test.

In Test 7, three Mk48 Simulators were placed in the donor cell. The test layout acceptor configuration was identical to those of previous tests. No propagation of detonation occurred to any of the acceptor charges. All acceptors were recovered from their packing cases undamaged.

In Test 8, one Mk45 mockup in its packing case was used as the donor. The acceptor configuration in Cell 11 had two Mk48 mockup weapons in their packing containers while Cell 1 contained only one Mk45 mockup weapon in its packing container. No propagation occurred to any of the acceptor weapons. Although the two Mk48 acceptors (in their XM467 containers) were slammed against the back wall, the mockups were apparently undamaged. Other weapons also were found undamaged after removal from their damaged packing containers.

Since a number of Mk48 had been recovered in undamaged condition it was decided to obtain additional information about the propagation characteristics of these Mk48 units. Two additional igloos were made available for these tests, which were performed without partitioning the igloos as in previous tests. Reference 10 gives the results of these tests which are classified.

The first eight tests were equipped with Kistler transducers to record pressure time history of the detonation at various points in the igloo. A comparison of the expected reflected pressure with actual recorded pressures shows that in general the actual pressures are slightly higher than had been expected on the basis of predicted pressures in Reference 10. Reflections within the igloo and from the dividing walls (sandbags) could account for these higher values. However, the data seems to be consistent within itself except for a few readings in Test 6. A summary of pressure data in this test series is contained in Reference 10, Table VI.

The fourth and final series was conducted at NAD in May 1965. This series consisted of 18 tests -- the main objective being to establish the threshold level for propagation through

sandbag walls two-feet-thick to selected weapons in normal storage configurations. The results indicate that sandbag-dividing walls constructed in explosive storage structures significantly decrease the probability of propagation of an accidental HE weapon detonation through the walls to other weapons. The details of this test series are in Reference 11 which is classified.

SECTION 5

EVALUATION OF STEEL PROTECTIVE CYLINDER

The purpose of this test was to provide qualitative information on the possible improvement of existing reinforced concrete explosive storage magazines by the addition of steel cylinders in the existing donor and acceptor cubicles. A 1/3 scale model test was designed to investigate physical damage to the acceptor cylinder and to measure wall fragment velocities resulting from the detonation of 16 lbs. (430 lbs. equivalent in the full-scale structure) of the donor in a corrugated steel cylinder within the cubicle.

The test was performed in January 1965 at NOTS, using the steel tunnel test facility. Still and high-speed motion cameras were used. Figures 88 and 89 show the test set-up. Round 1 consisted of a donor charge (16 lbs.) located inside the scaled-down corrugated pipe with another corrugated pipe located inside the tunnel as an acceptor. The acceptor was separated from the donor pipe by a scaled-down standard reinforced-concrete slab located at the opening of the support tunnel. This round was to investigate the effects of blast and fragments on a steel cylinder in the acceptor cell. The 16-lb. HE charge (which was detonated from both ends simultaneously) resulted in a complete destruction of the donor cylinder and test slab. The acceptor cylinder was so collapsed that the opposite sides touched each other at the center (Figure 90).

The test result was considered a failure. To investigate the possibility that the excessive damage to the acceptor cylinder resulted from possible jetting action caused by initiation of the donor at both ends simultaneously, the test was repeated with donor charge detonated at one end only. The only available steel cylinder was used in the acceptor cell. However, detonation of the donor resulted in the same type of damage as with the first round (Figure 91).

From the test results thus far, no final estimate of the effect of using a steel cylinder could be made. The basis on which the recommendation was originally made apparently was overly optimistic. After recalculation of the design parameters, an additional test will be performed if it appears that an economic advantage is still possible.

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SECTION 6

EVALUATION OF ACCEPTOR SENSITIVITY

Objective

The primary purpose of these tests was to determine the sensitivity of various HE warheads when subjected to multiple overpressure shock waves.

Background

Results of weapon-to-weapon propagation tests in 1964 and 1965 indicated that one possible cause of detonation propagation was initiation of acceptors by the overpressure resulting from the shock interaction. To further evaluate the problem of safe storage of weapons in subdivided igloos, it became necessary to evaluate the sensitivity of certain specific charges or weapons to high over-pressure applied to the outside of the weapon in such a manner that initiation might be caused by collapse of a steel container around an explosive charge at distances greater than those at which sympathetic detonation might be expected solely from blast pressures. The specific purpose of this test series is to investigate the initiation of an acceptor by pressure and shock conditions similar to those existing in an earth covered igloo.

Test Procedure

This test series will consist of detonating four 32-lb. spherical donor charges in a symmetrical array around HE warhead systems (Figure 92). The test series will be divided into two groups:

A. Calibration tests consisting of five or six tests using a dummy acceptor instrumented with four pressure transducers. Figure 93 shows the gage placement to be used. Donor spheres will be placed in a symmetrical array at positions which, it is predicted, will produce specific overpressures. It is intended to develop a calibration curve from this group of tests covering pressures at the acceptor from 300 to 4,000 psi.

B. The second group of tests will consist of about 20 to 25 tests. Donor charges will be placed at a distance which will produce a specific overpressure (from the calibration curve developed by Group A tests) at the HE warhead acceptor (in shipping container). If the warhead detonates, the test will be repeated at lesser over-pressures until no detonation occurs. If detonation

does not occur on the first test, the tests will be repeated at successively higher overpressures until detonation does occur.

High-speed camera coverage will be utilized on Group A tests to ascertain that all donor charges detonate simultaneously. No high-speed camera coverage or blast overpressure measurements will be required on Group B tests.

SECTION 7

DEVELOPMENT OF DESIGN PROCEDURES FOR REINFORCED CONCRETE STRUCTURES UTILIZED IN EXPLOSIVE STORAGE AND MANUFACTURING FACILITIES

This section summarizes the work being conducted in connection with the development of tentative procedures for the design of reinforced concrete structures used in explosive storage and manufacturing facilities. A brief discussion of the elements involved in the design is followed by a presentation of a portion of test results utilized in the development of these procedures.

Donor System

Because of the nature of the confinement of an explosion within a cubicle, the blast loads acting within the structure will be characterized by extremely high overpressures. However, because of the short durations, structures can be designed for the dynamic impulse loading rather than for the peak overpressures required for the relatively long duration associated with a nuclear explosion.

In confined quarters, there will exist a multiplication of initial blast output (free air pressure) due to blast interaction with the various reflecting surfaces (floor, walls, roof, etc.) within the structure. At any given point on a particular reflecting surface, the total impulse is a result of contributions from that surface and from adjacent reflecting surfaces. This total impulse is greater than that produced by the particular surface alone but is less than the total addition of each reflecting impulse contribution.

At present, analyses using manual calculations are available which predict the impulse loads, including the previously mentioned contributions. Figure 94 shows some curves obtained. In these curves, the individual impulse load for a given scaled distance is an average value of the loads applied to various points on the surface of the wall. This average impulse load is dependent on the particular cubicle arrangement and the specific charge location.

Although the predicted loads are determined by a semi-empirical procedure which does not account for the actual wave interaction phenomenon, past tests have substantiated the end results of the analyses (future tests are contemplated). In Tables 21 and 22, the average value of the impulse loads as calculated by the semi-empirical procedure were compared with results of cubicle tests performed at the Naval Weapon Laboratories (Reference 2). The individual test results of Table 21 and 22 represent an average value of individual impulse gage readings for one particular wall in one specific test.

The hand calculations are now being supplemented by more detailed computer analyses. The analytical impulse loads will include a wide variation of the chart variables, structure configuration and size, charge location and charge weight.

Insofar as blast pressures at the exterior of the explosive structure are concerned, a recommended procedure for determining the design pressure blast loads for other structures located in the vicinity of the structure containing the explosive donor system was developed. The recommended loads are based on theoretical relationships in addition to the data from the test results.

Protective Barricades

The required capacity of a barrier for a particular mode of action is calculated by equating the potential energy of the barrier to the kinetic energy associated with the momentum of the barrier resulting from the applied blast load. In the cases where structural integrity is maintained, the potential energy of the barrier is in the form of flexural action of the structural barrier plus energy attenuation through absorbing materials used in sandwich construction. For those structures where collapse is permitted, the potential energy of the barrier is expressed in terms of the flexural action and energy absorption plus the kinetic energy of the discharge fragments.

An example of a manual calculation giving the response of a back wall of a cubicle is in Reference 7. This example indicates the method of computing the wall resistance, mass resistance deflection and other dynamic properties. These are in turn used to calculate the wall impulse capacity. For incipient

TABLE 21

COMPARISON OF CALCULATED AVERAGE IMPULSE WITH TEST RESULTS (BACK WALL)

Cell Parameters		Charge Parameters						Average Impulse		Ratio
H (in)	$\frac{L}{H}$	W (lbs)	R (in)	Z_A ($ft/lb^{1/3}$)	$\frac{\ell}{L}$	$\frac{h}{H}$	Z_B/Z_A	Test (psi-ms)	Cal. (psi-ms)	Cal./Test
10	1.70	1.4	5.5	0.41	0.50	0.50	1.55	943	984	1.05
		2.6	5.5	0.34	0.50	0.50	1.55	1588	1755	1.10
		1.4	11.0	0.83	0.50	0.50	0.77	675	855	1.26
		2.6	11.0	0.67	0.50	0.50	0.77	1265	1510	1.20
16	1.06	1.4	5.5	0.41	0.50	0.25	1.55	811	830	1.03
		2.6	5.5	0.34	0.50	0.25	1.55	1617	1515	0.94
		1.4	11.0	0.83	0.38	0.50	0.77	733	710	0.97
		2.6	11.0	0.67	0.38	0.50	0.77	1310	1440	1.10
								Average Ratio Cal./Test		1.08
								Standard Deviation		10.3%

Glossary:

- H - Wall Height
- L - Wall Length
- W - Weight
- R - Distance
- Z_A - Normal Scaled Distance
- ℓ - Distance between Charge and Adjacent Wall
- Z_B - Scaled Distance from Center of the Cubicle to Adjacent Wall
- h - Charge Height

TABLE 22

COMPARISON OF CALCULATED AVERAGE IMPULSE WITH TEST RESULTS (SIDE WALL)

Cell Parameters		Charge Parameters						Average Impulse		Ratio
H (in)	$\frac{L}{H}$	W (lbs)	R (in)	Z_A (ft/lb$^{1/3}$)	$\frac{\ell}{L}$	$\frac{h}{H}$	Z_B/Z_A	Test (psi-ms)	Cal. (psi-ms)	Cal./Test
10	2.20	1.4	8.5	0.63	.50	.50	1.30	543	530	0.98
		2.6	8.5	0.52	.50	.50	1.30	996	950	0.96
		1.4	12.8	0.96	.50	.50	0.86	483	495	1.03
		2.6	12.8	0.78	.50	.50	0.86	847	825	0.97
16	1.38	1.4	6.4	0.48	.50	.50	1.72	474	487	1.03
		2.6	6.4	0.38	.50	.50	1.72	831	780	0.95
		1.4	8.5	0.63	.75	.25	1.30	342	376	1.10
		1.4	8.5	0.63	.75	.25	1.30	345	376	1.09
							Average Ratio Cal./Test			1.01
							Standard Deviation			5.5%

For Glossary of Terms See Table 21

failure criteria, the impulse capacity of the wall is equal to the impulse of the applied loads of the blast, whereas for personnel protection the impulse capacity of the wall must be substantially larger than that of the applied loads.

The procedure for determining the response of reinforced-concrete cubicle type structures to explosives was derived from experimental data from both cubicle model tests and component slab test (1/3 scale slab test) performed in conjunction with this program. Also developed with these tests were special detailing methods necessary to obtain strength and ductility in excess of values associated with standard construction.

Table 23 is a comparison of the results of a selected number of slab tests with the results from analytical procedures. In the semi-empirical analyses the actual permanent deflections of the slabs as determined from the test results were used to evaluate the slab impulse capacities. These impulse capacities were then compared to the empirical impulse loads previously described. The methods of calculation of impulse capacity for back and side walls of cubicle structures are being adapted for computer analyses. From the results of these analyses, design curves will be available which will plot impulse capacities for various concrete wall geometries (length, height, thickness percent tension reinforcement, shear reinforcement, sandwich construction, etc.). The calculated charge capacities were based on impulse loads from semi-empirical impulse charts.

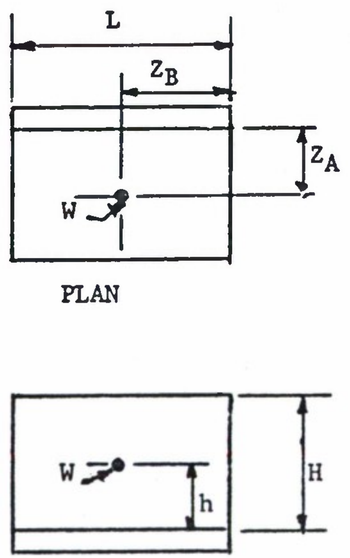
Model Tests

Upon completion of the design charts, selected panels (both back and side walls) will be used to design model cubicle structures. The models will be tested to verify the design procedure.

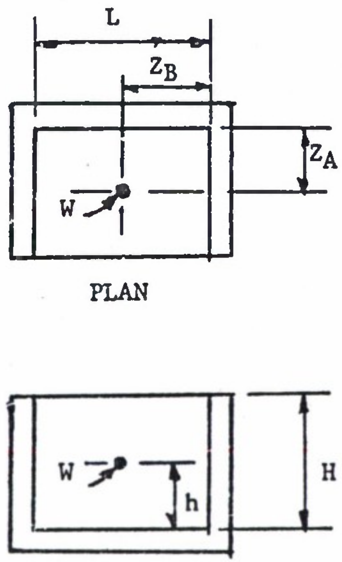
TABLE 23

COMPARISON OF RESULTS OF REINFORCED CONCRETE SLAB TESTS WITH CALCULATED CHARGE CAPACITIES

Test	Round	Slab	1/3 SCALE TEST SLAB				TEST ARRANGEMENT					W	W	$\frac{W(Calc.)}{W(Test)}$
			Span (ft)	Thick (in.)	% Reinf.	Type	Type	L/H	Z_B/Z_A	h/H	Z_A	(Test)	(Calc.)	
3	2	1	2.0	4	1.40	Solid	1	0.68	0.463	0.55	0.8	20	25	1.2
3	8	2	2.0	4	2.70	Solid	2	1.05	1.00	0.55	0.5	30	35	1.1
2	20	3	2.0	12	1.33	Solid	2	1.03	1.30	0.58	0.4	30	30	1.0
3	11	4	2.0	4(6)	0.65	Comp.	1	0.61	0.65	0.59	0.5	30	40	1.3
2	18	5	2.0	4(12)	1.40	Comp.	2	1.03	1.30	0.58	0.4	30	25	.8
3	12	6	2.0	4(12)	2.70	Comp.	1	0.61	0.51	0.59	0.5	60	55	.9
3	13	7	2.0	6(8)	2.70	Comp.	2	0.86	0.87	0.34	0.38	60	65	.9



NO SIDE WALLS (TYPE 1)



TWO SIDE WALLS (TYPE 2)

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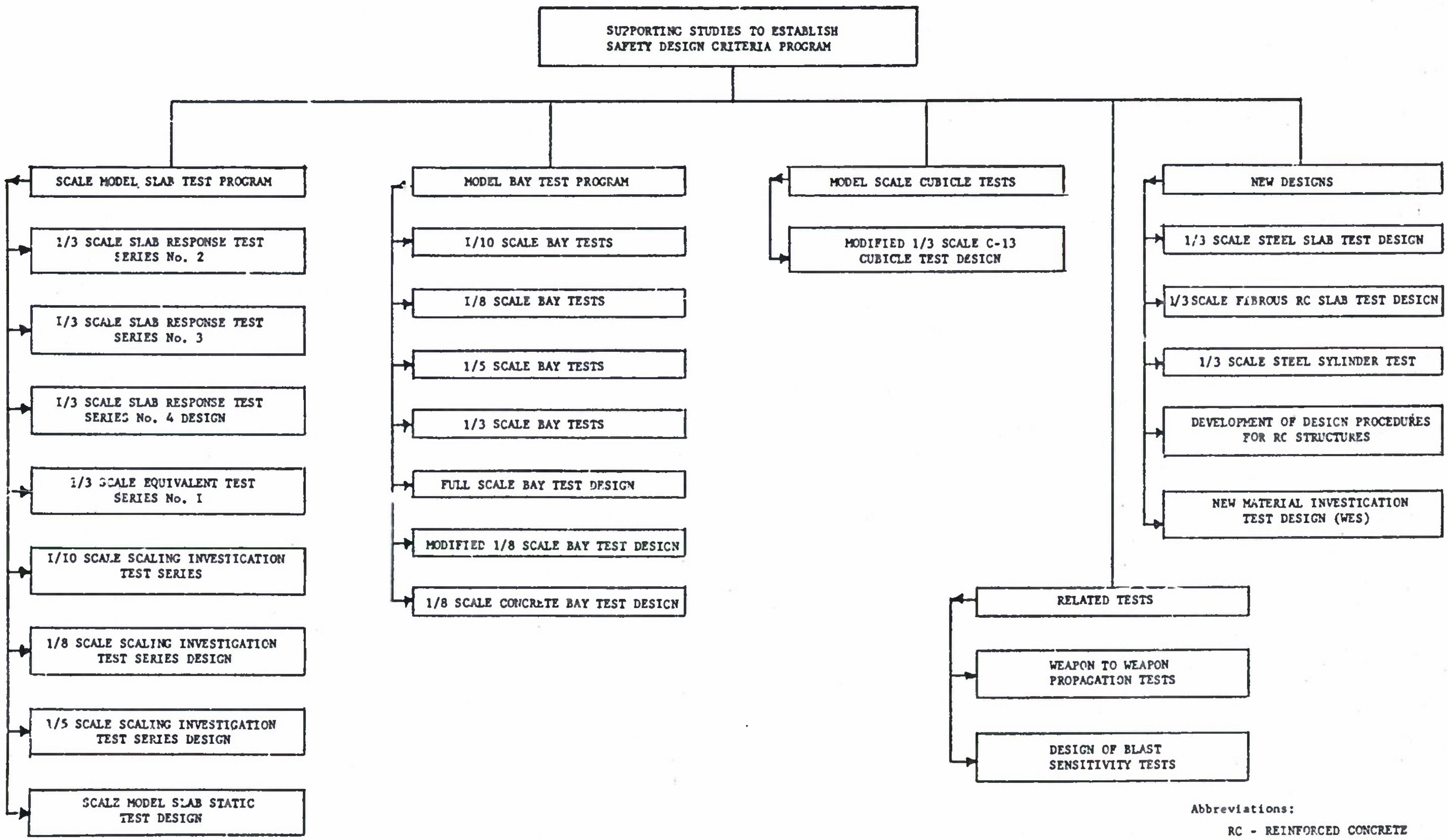
APPENDIX A

Figures



Abbreviations:

RC - REINFORCED CONCRETE

(WES) - WATERWAYS EXPERIMENTAL STATION

FIGURE 1
ORGANIZATION OF SUPPORTING STUDIES PROGRAM

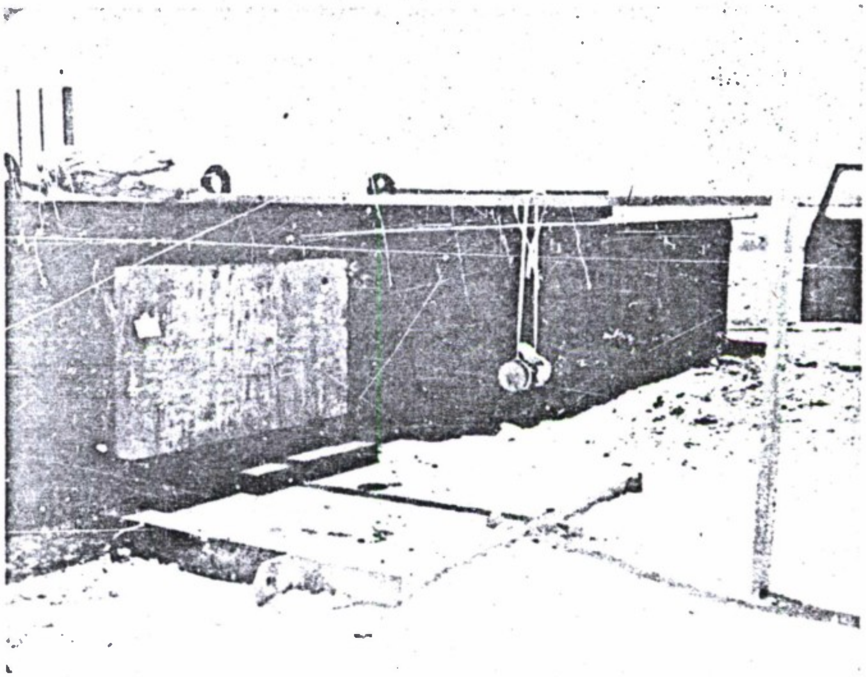


FIGURE 2

STEEL SUPPORT TUNNEL SHOWING
TEST SLAB AND CHARGE

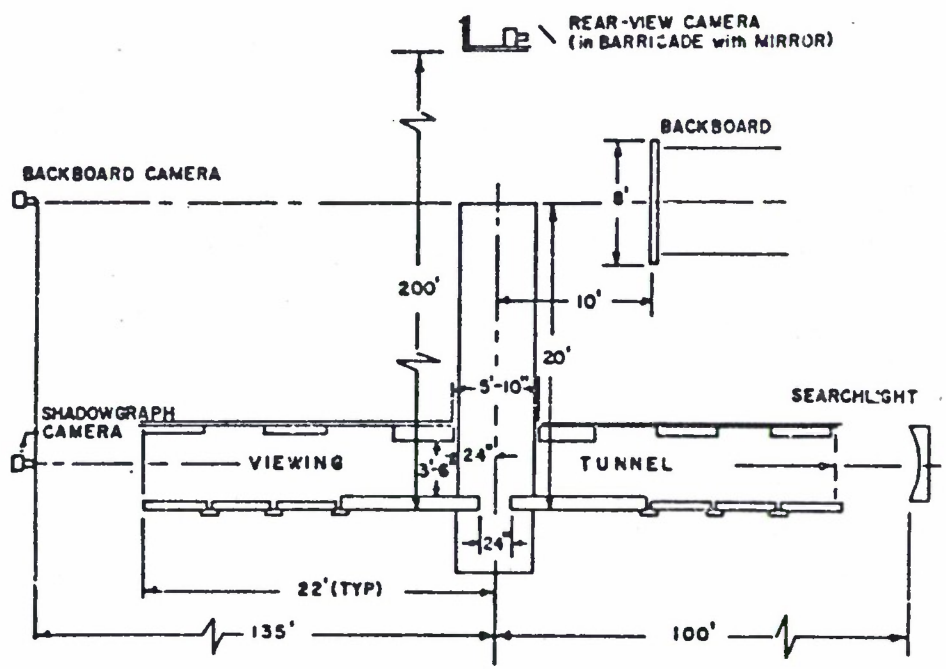


FIGURE 3
VERTICAL SUPPORT TUNNEL AND CAMERA SETUP

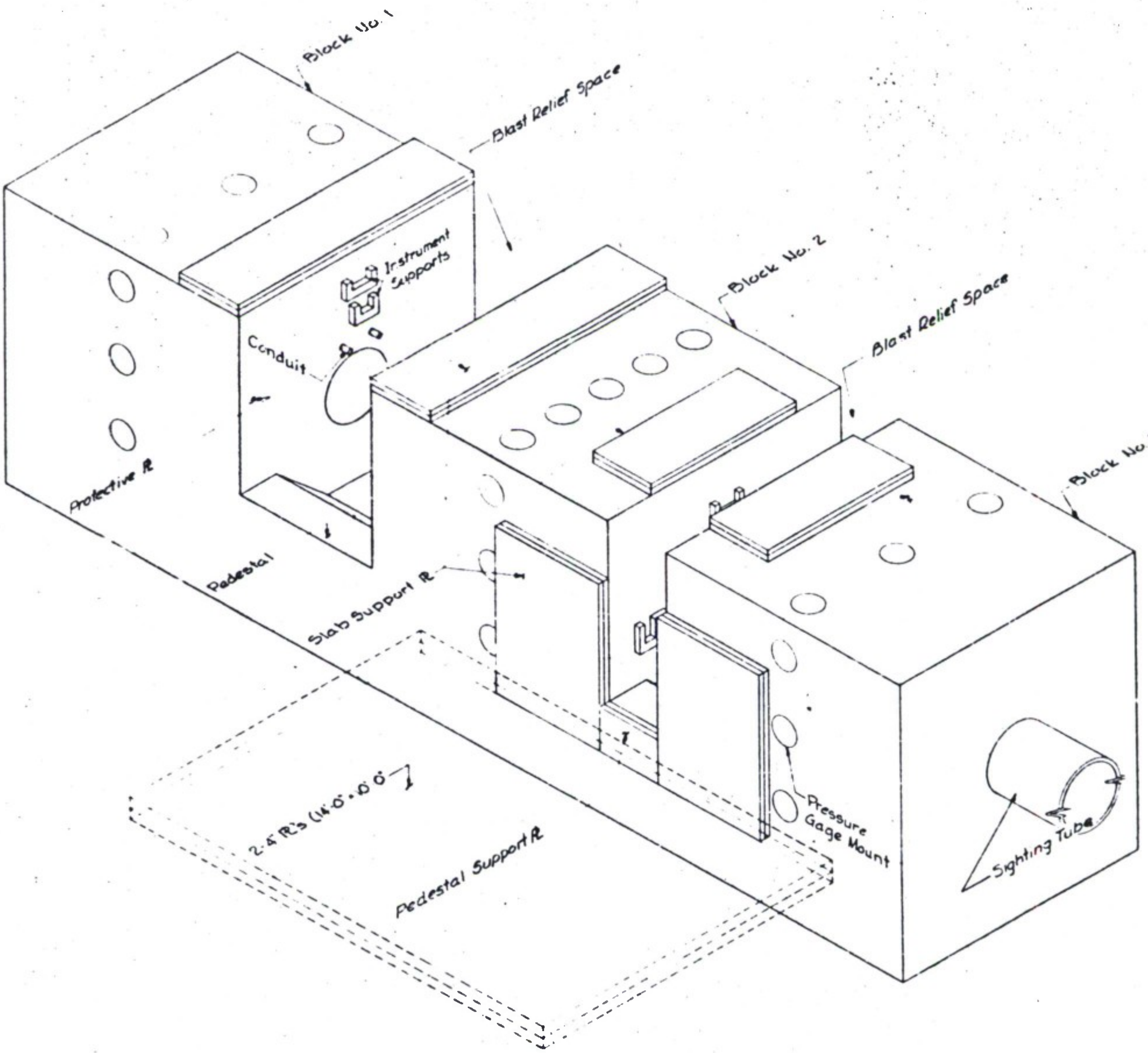


FIGURE 4
OVERALL VIEW OF SLAB SUPPORT STRUCTURE

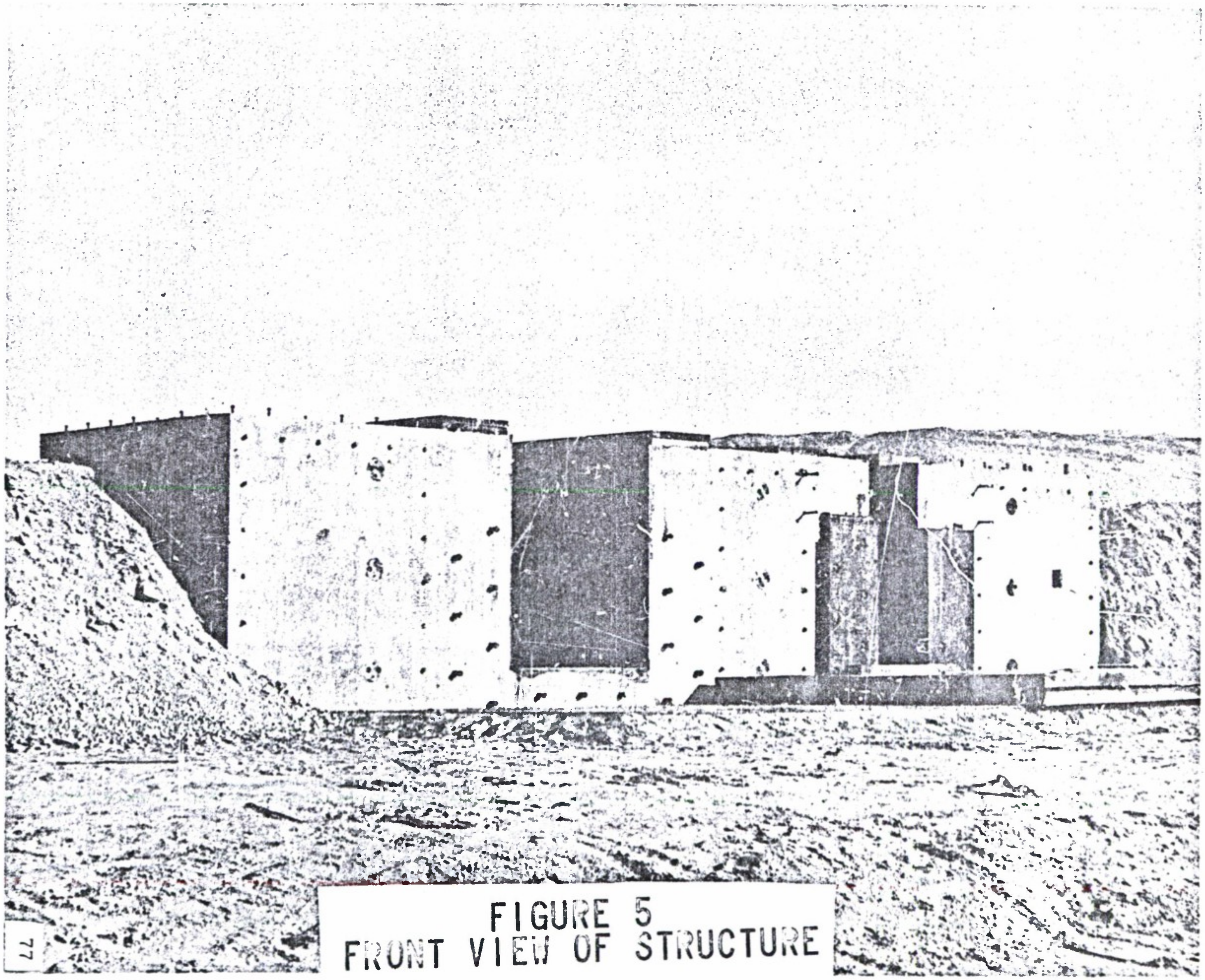


FIGURE 5
FRONT VIEW OF STRUCTURE

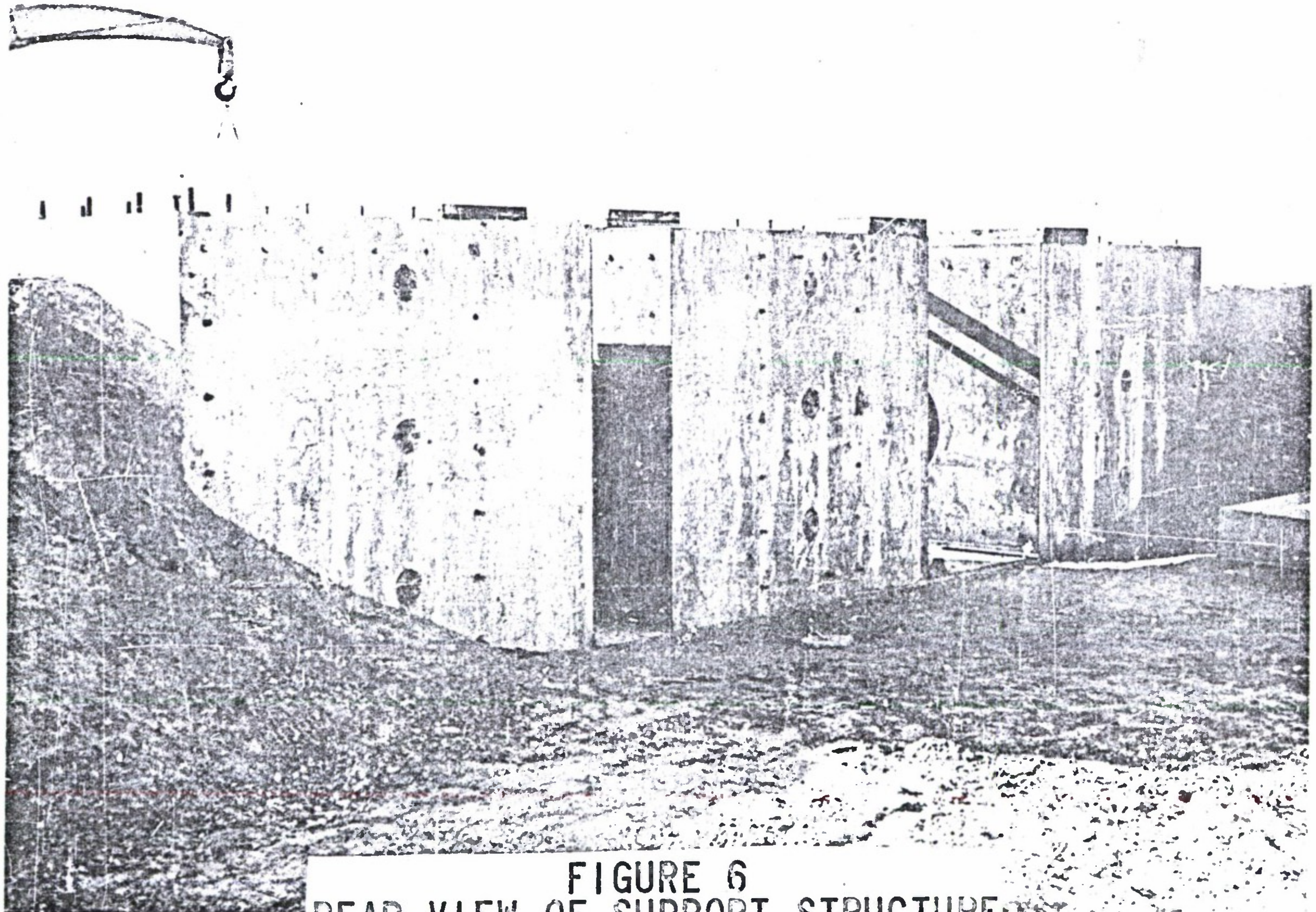


FIGURE 6
REAR VIEW OF SUPPORT STRUCTURE

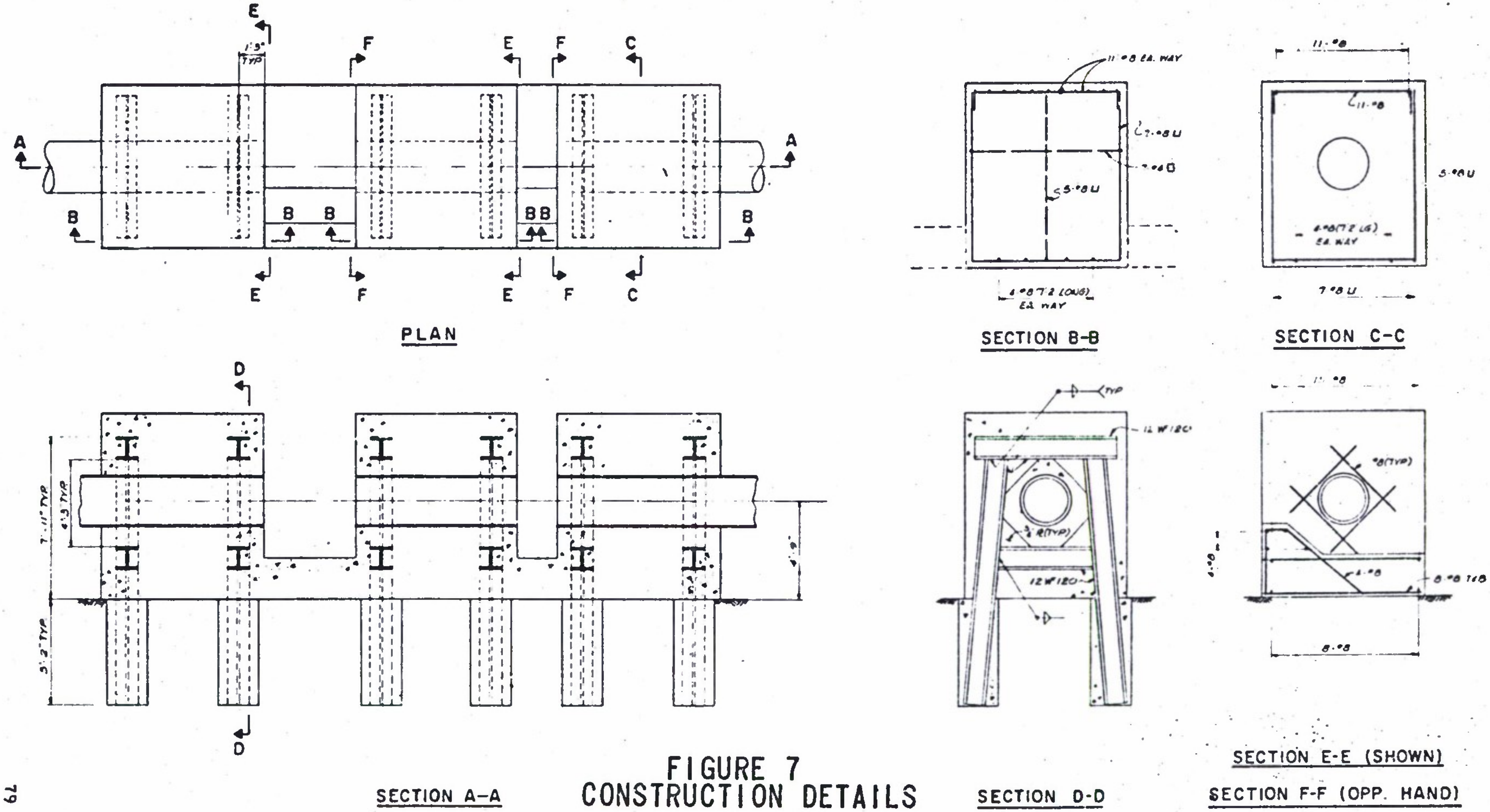


FIGURE 7
CONSTRUCTION DETAILS

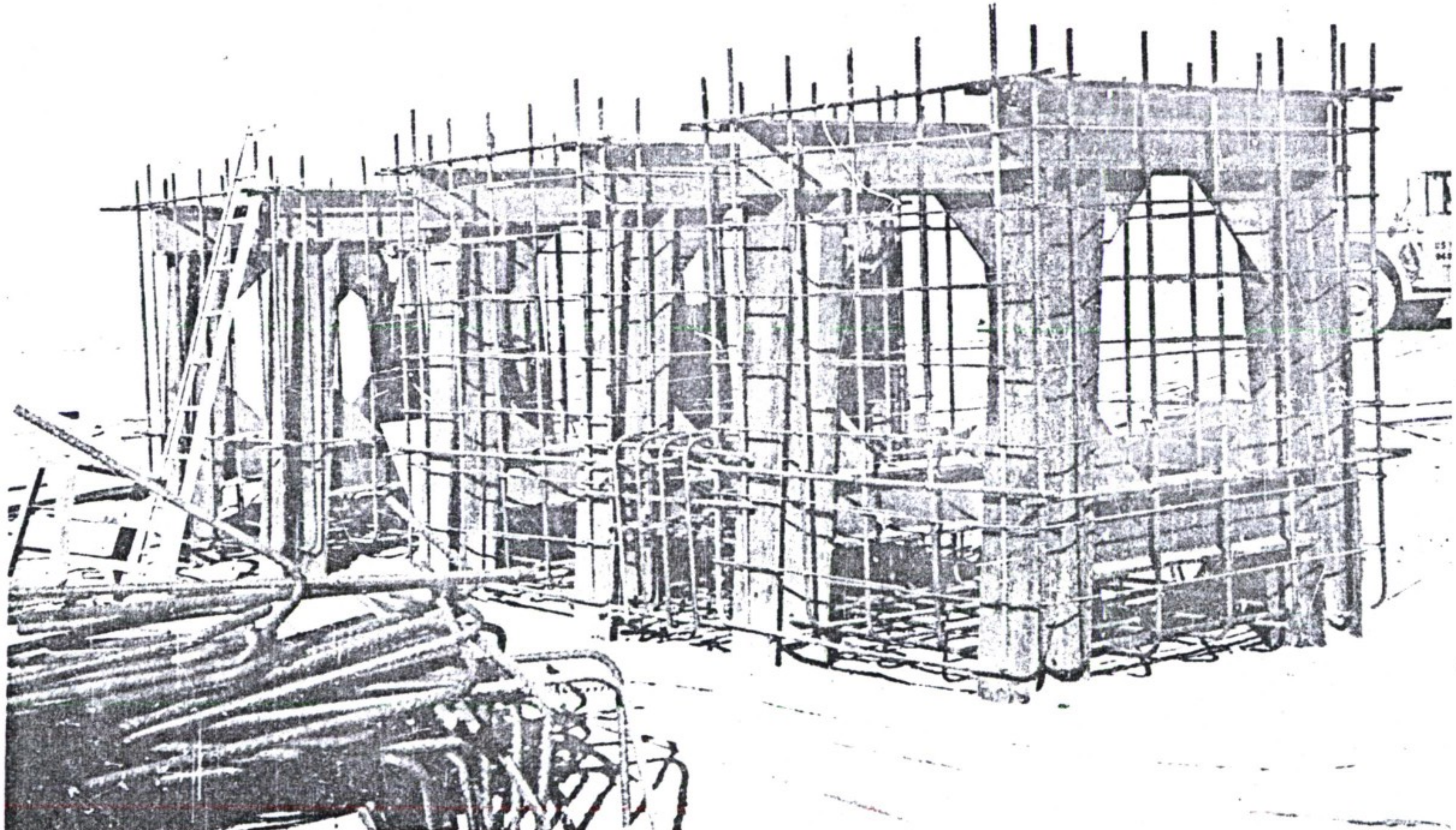


FIGURE 8
OVERALL VIEW OF REINFORCEMENT

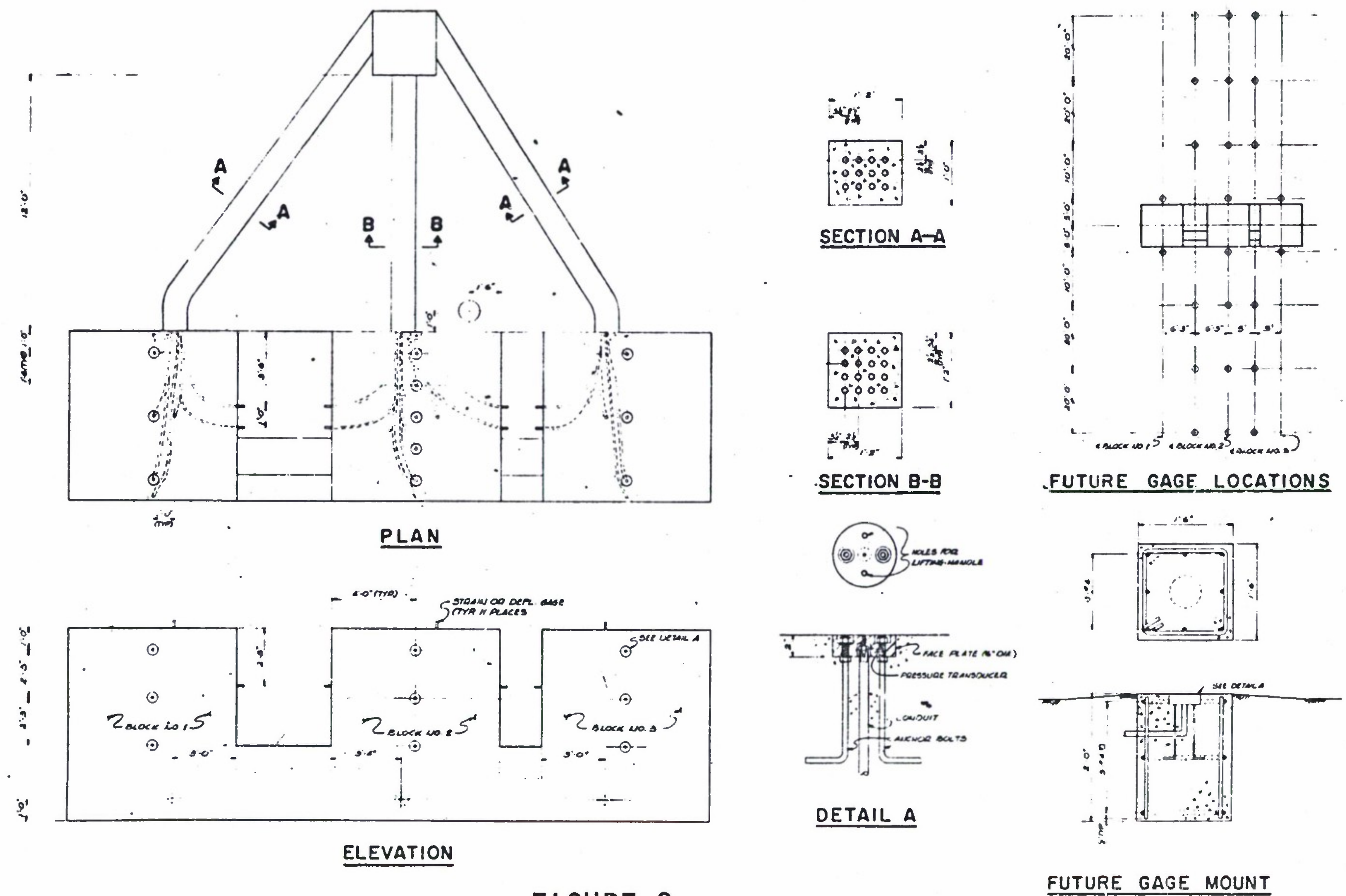


FIGURE 9
PRESSURE RECORDING AND ELECTRICAL FACILTIES

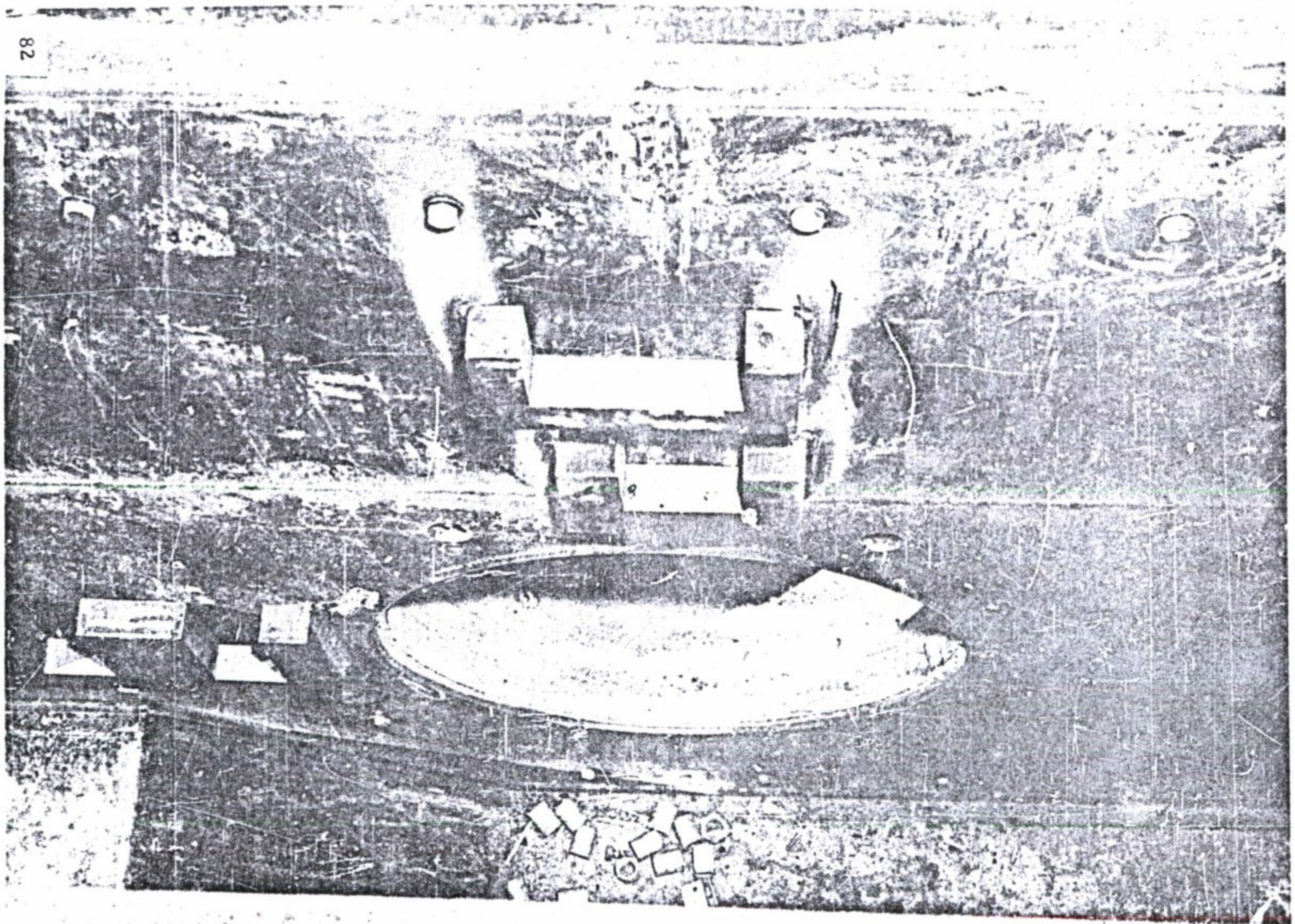


FIGURE 10
INSTRUMENTATION SUPPORTS

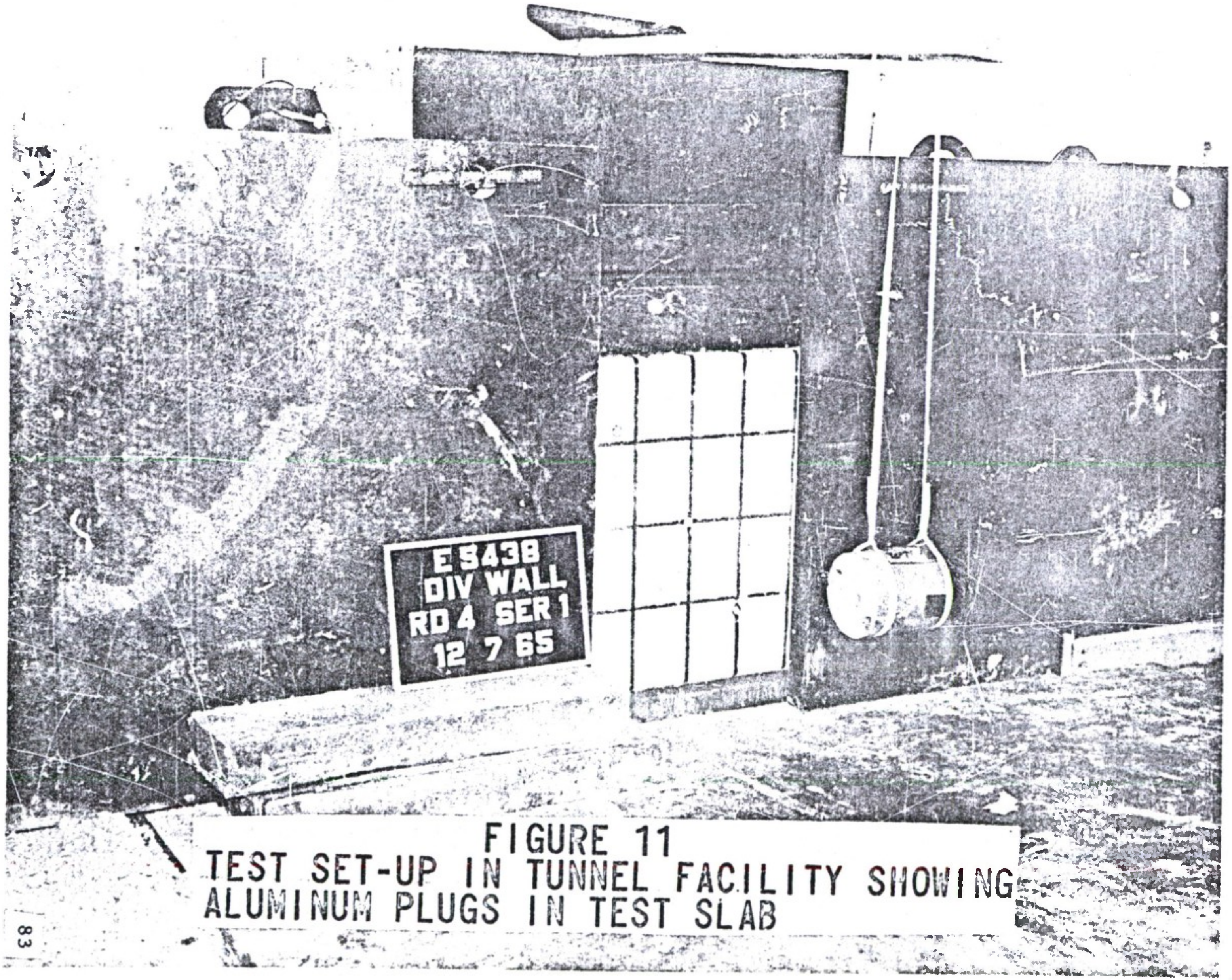


FIGURE 11
TEST SET-UP IN TUNNEL FACILITY SHOWING ALUMINUM PLUGS IN TEST SLAB

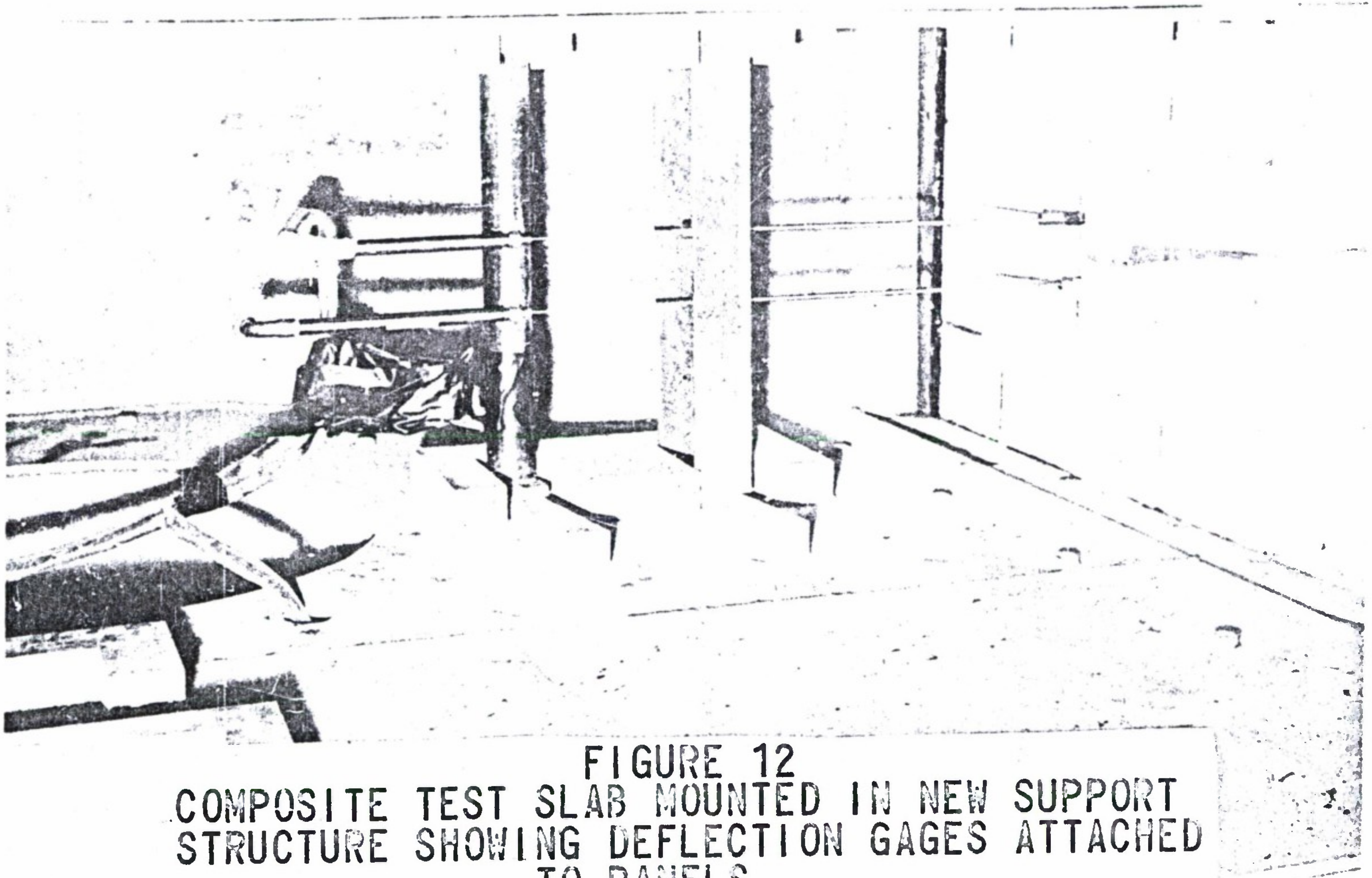


FIGURE 12
COMPOSITE TEST SLAB MOUNTED IN NEW SUPPORT STRUCTURE SHOWING DEFLECTION GAGES ATTACHED TO PANELS

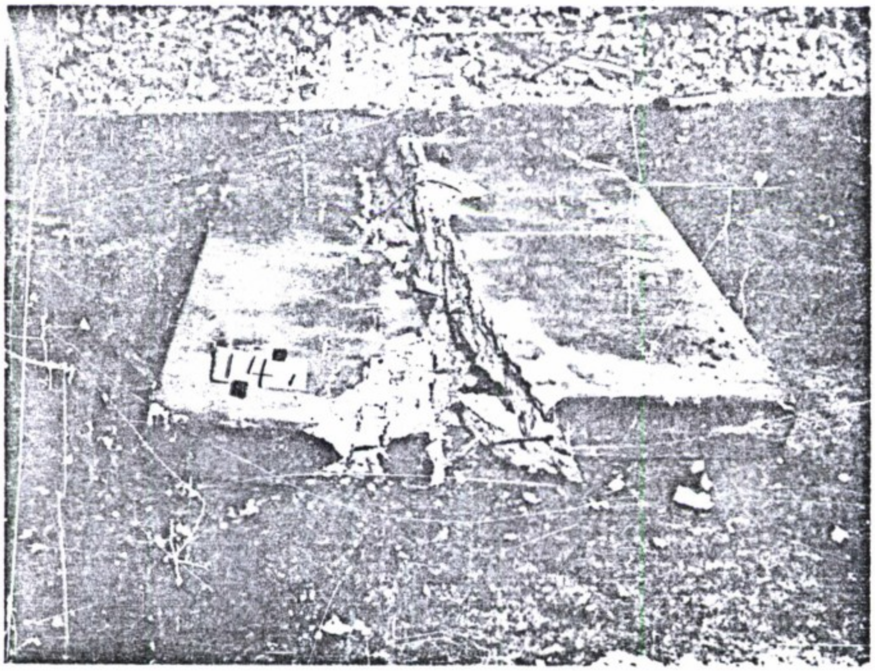


FIGURE 13
ROUND 14-1 -- STANDARD SLAB
10 LBS. HE, Z = 1.5

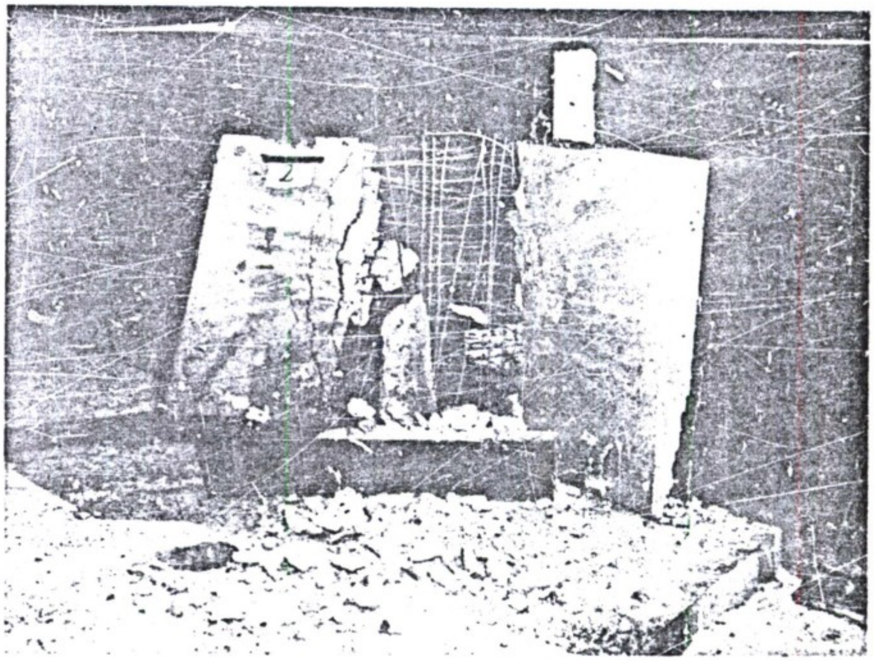


FIGURE 14

ROUND 2-1 -- STRENGTHENED SLAB 2
10 LBS. HE Z = 0.5

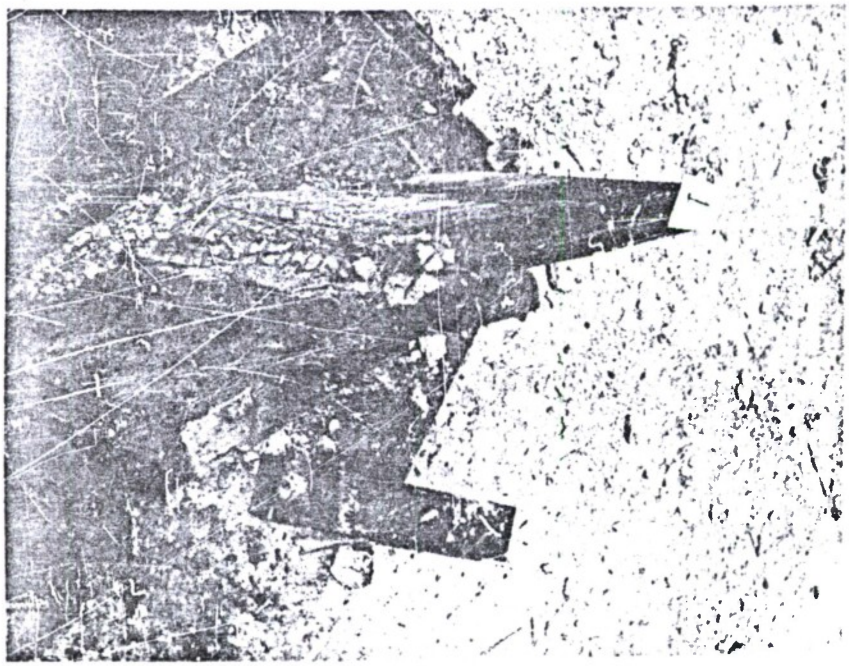


FIGURE 15
ROUND 1-1 -- STRENGTHENED SLAB 2
10 LBS. HE Z = 1.25

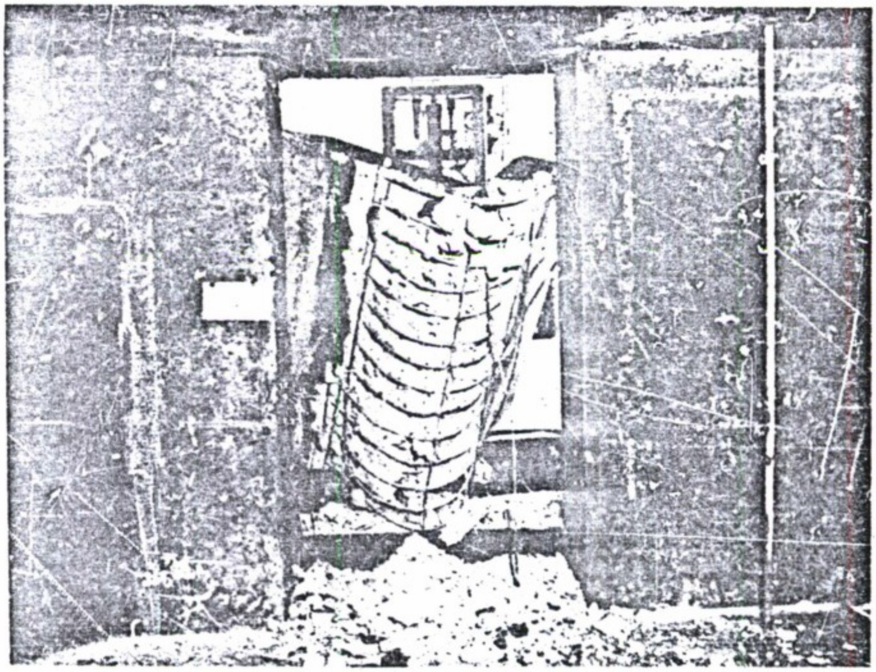


FIGURE 16
ROUND 4-1 -- STRENGTHENED SLAB 3
10 LBS. HE   Z = 0.5

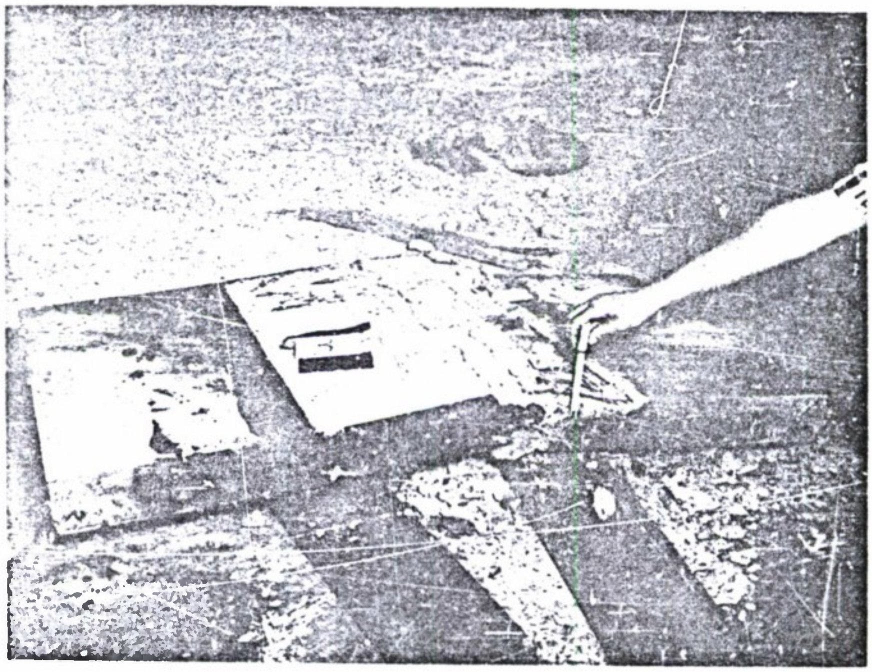


FIGURE 17
ROUND 3-1 -- STRENGTHENED SLAB 3
10 LBS. HE   Z = 1.25

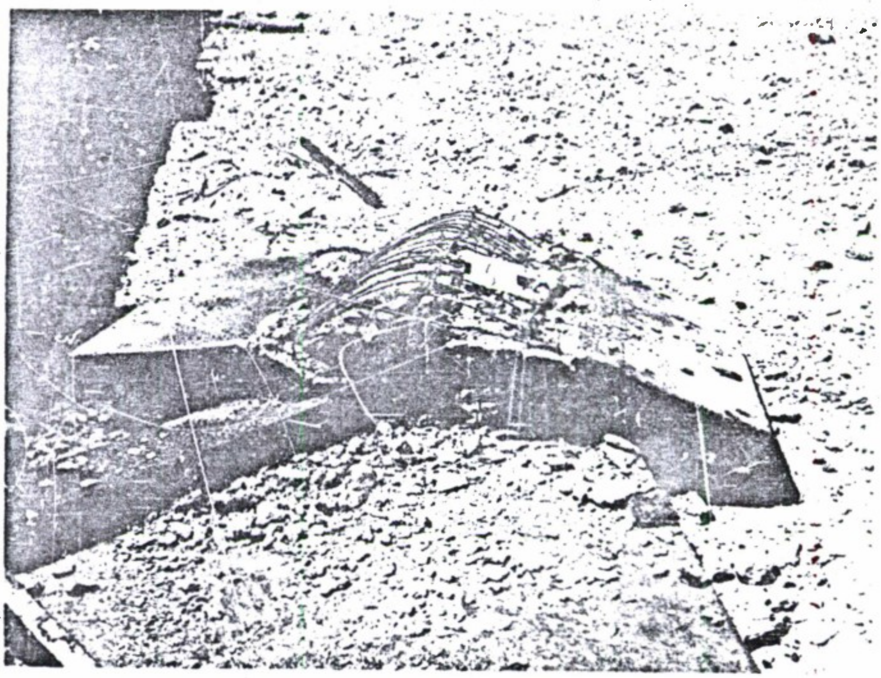


FIGURE 18
ROUND 5-1 -- STRENGTHENED SLAB 4
10 LBS. HE, Z = 0.5

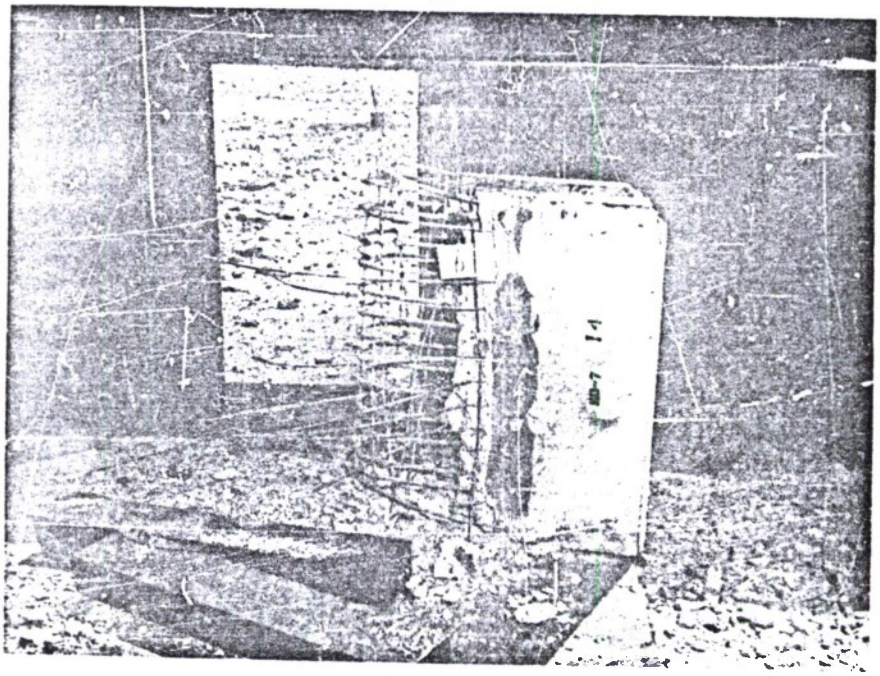


FIGURE 19
ROUND 6-1 -- STRENGTHENED SLAB 4
20 LBS. HE Z = 0.5

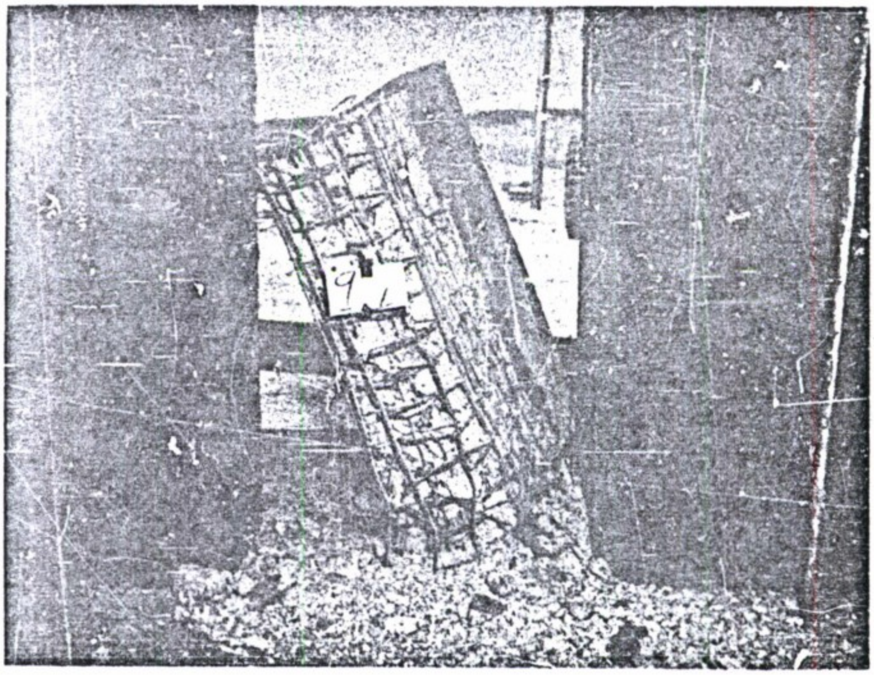


FIGURE 20
ROUND 9-1 -- STRENGTHENED SLAB 6
20 LBS. HE, Z = 0.5

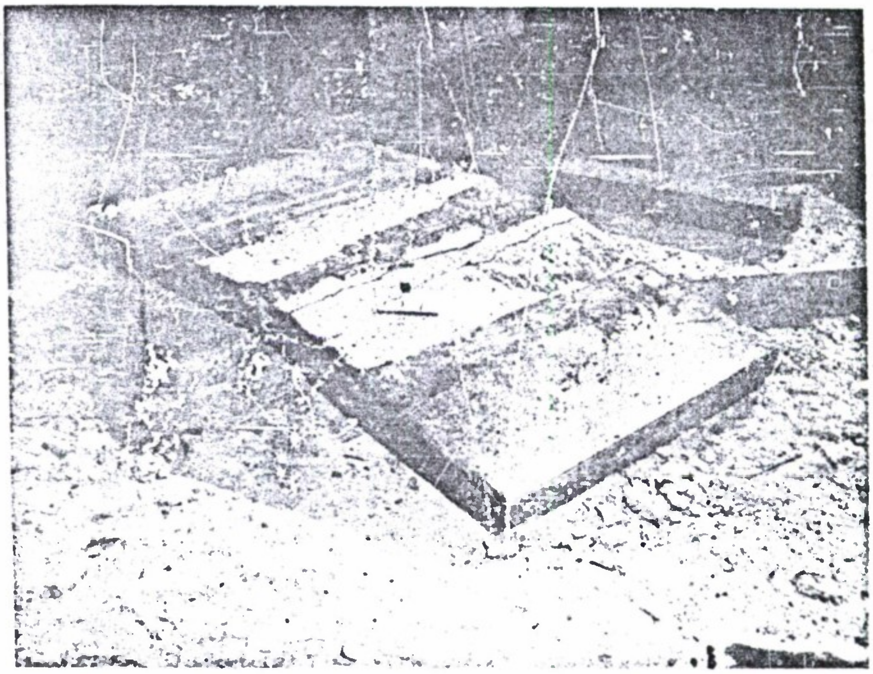


FIGURE 21
ROUND 8-1 -- STRENGTHENED SLAB 6
20 LBS. HE Z = 1.25

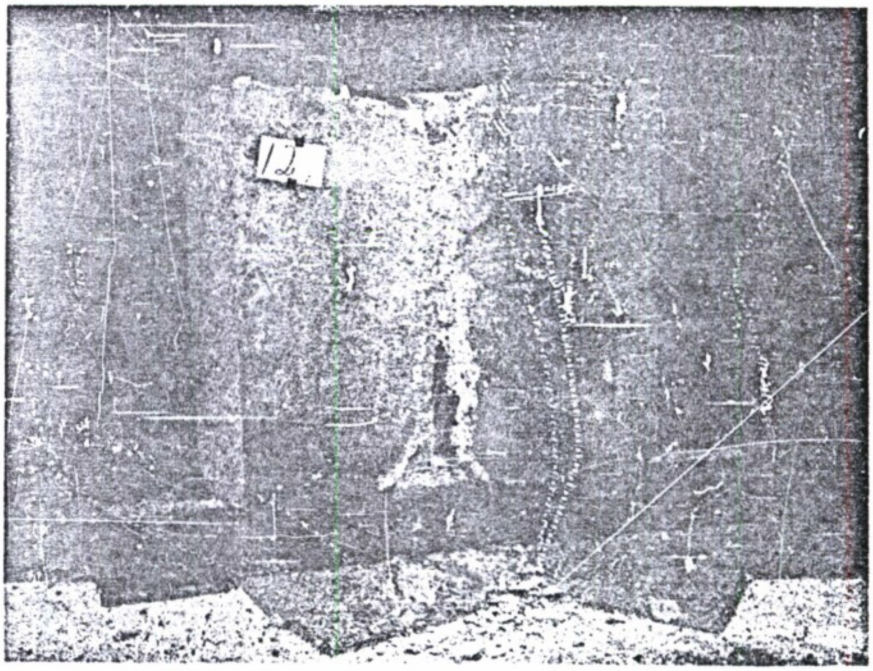


FIGURE 22
ROUND 12-1 -- STRENGTHENED SLAB 7
30 LBS. HE   Z = 0.5

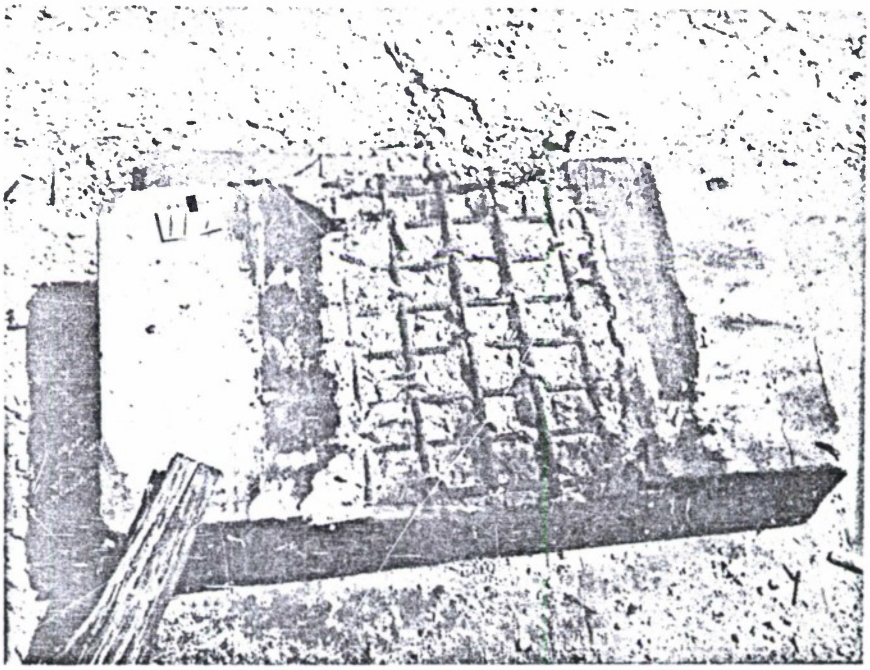


FIGURE 23
ROUND 11-1 -- STRENGTHENED SLAB 8
30 LBS. HE   Z = 0.5

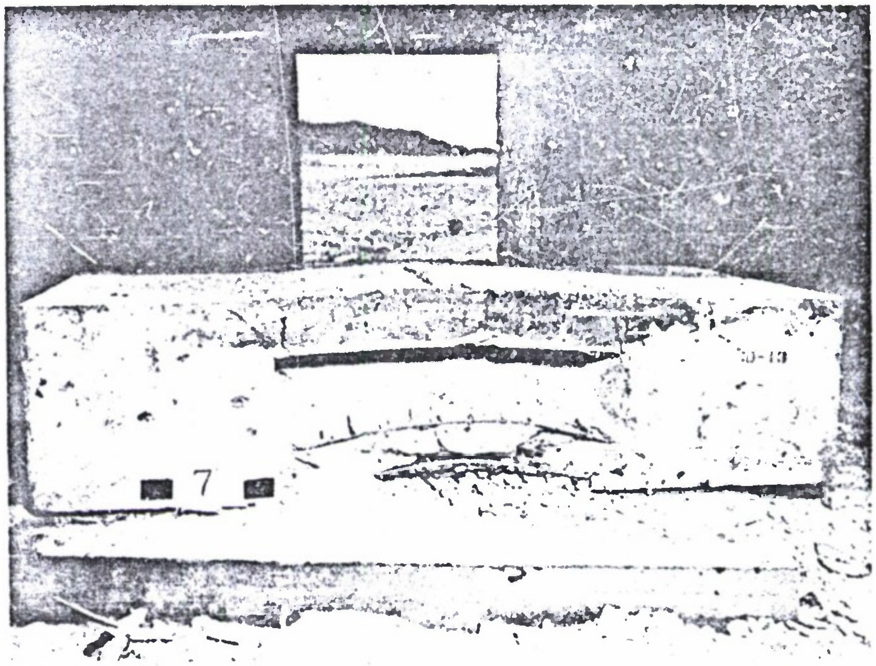


FIGURE 24
ROUND 7-1 -- COMPOSITE SLAB 2
20 LBS. HE Z = 0.5

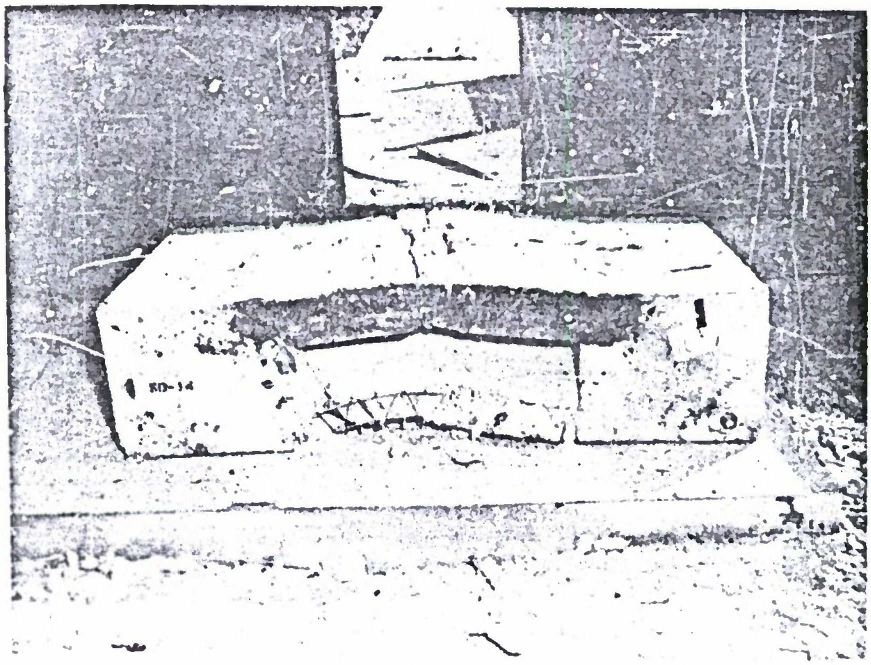


FIGURE 25
ROUND 10-1 -- COMPOSITE SLAB 3
30 LBS. HE   Z = 0.5

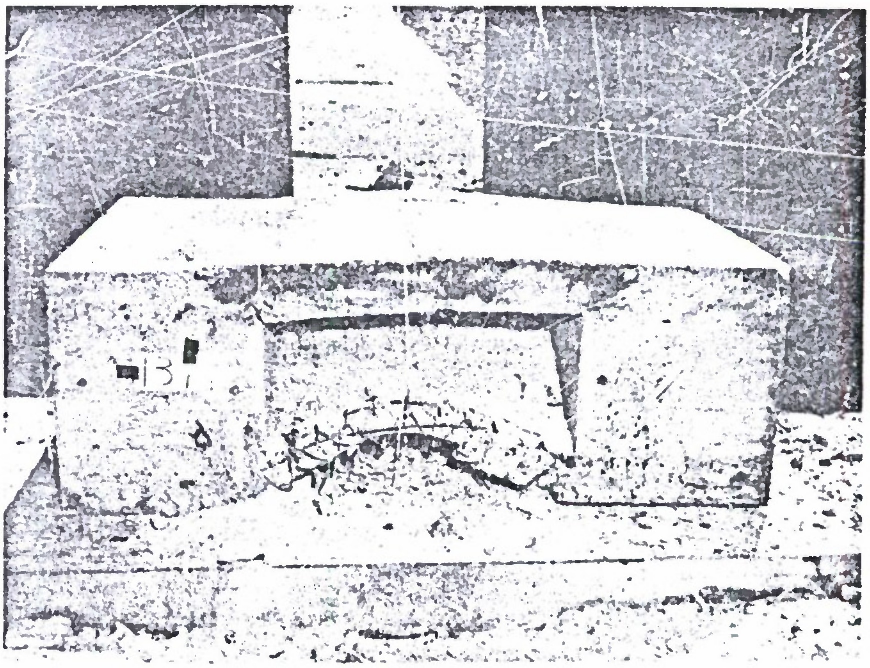


FIGURE 26
ROUND 13-1 -- COMPOSITE SLAB 4
30 LBS. HE Z = 0.4

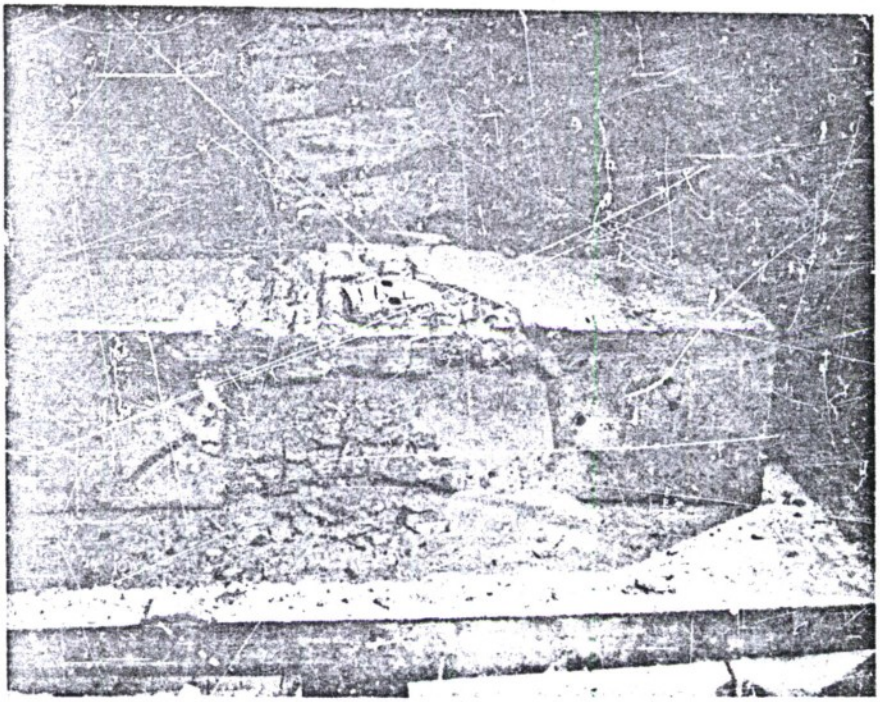


FIGURE 27
ROUND 16-1 -- COMPOSITE SLAB 5
30 LBS. HE Z = 0.5

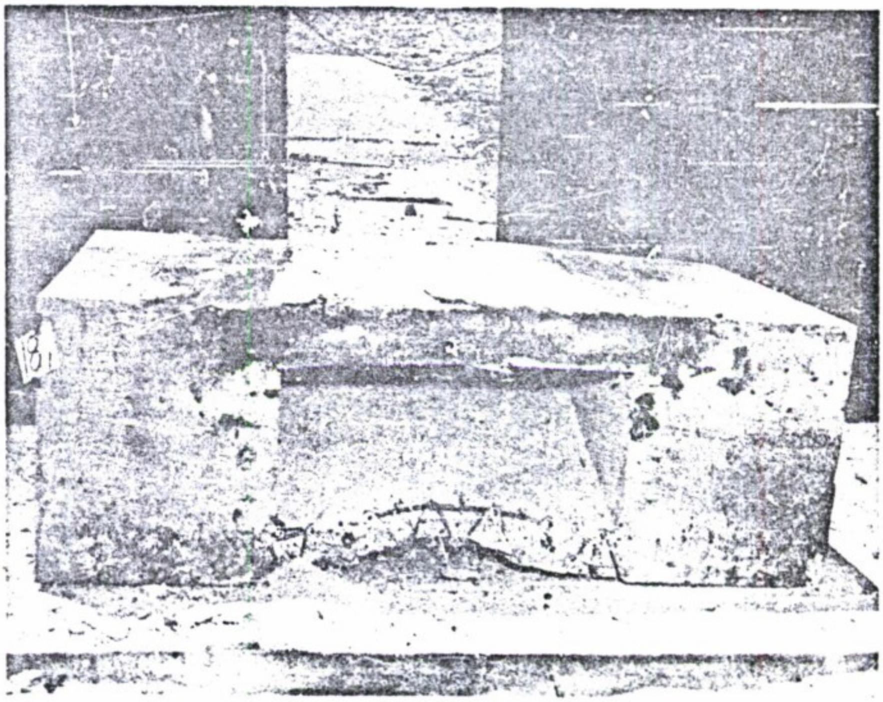


FIGURE 28
ROUND 18-1--COMPOSITE SLAB 6
30 LBS. HE Z = 0.4

FIGURE 29
ROUND 19-1 -- COMPOSITE SLAB 6
40 LBS. HE   Z = 0.4

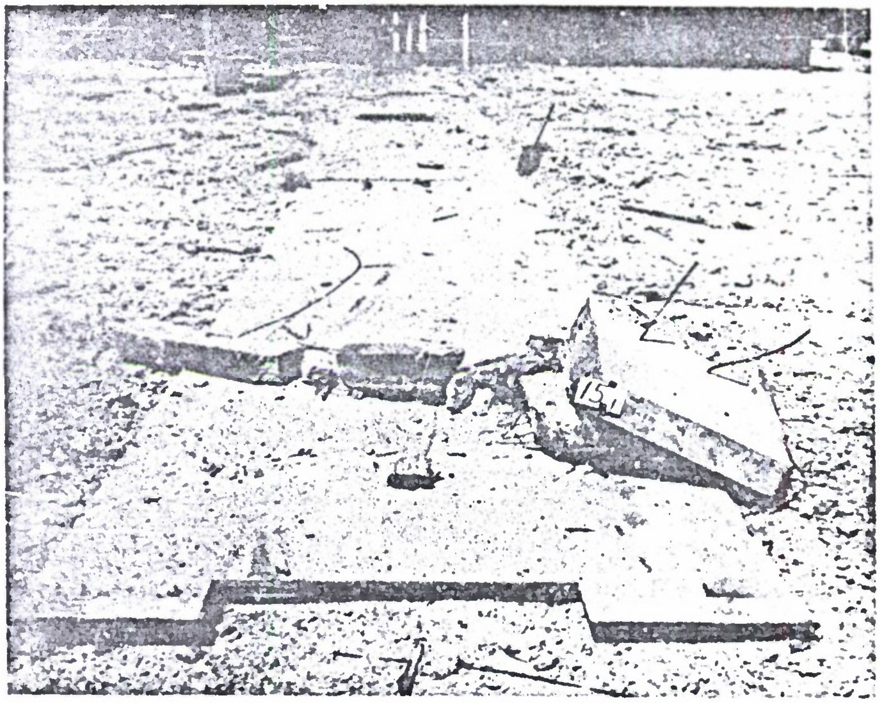


FIGURE 30
ROUND 15-1 -- COMPOSITE SLAB 7
30 LBS. HE Z = 0.5

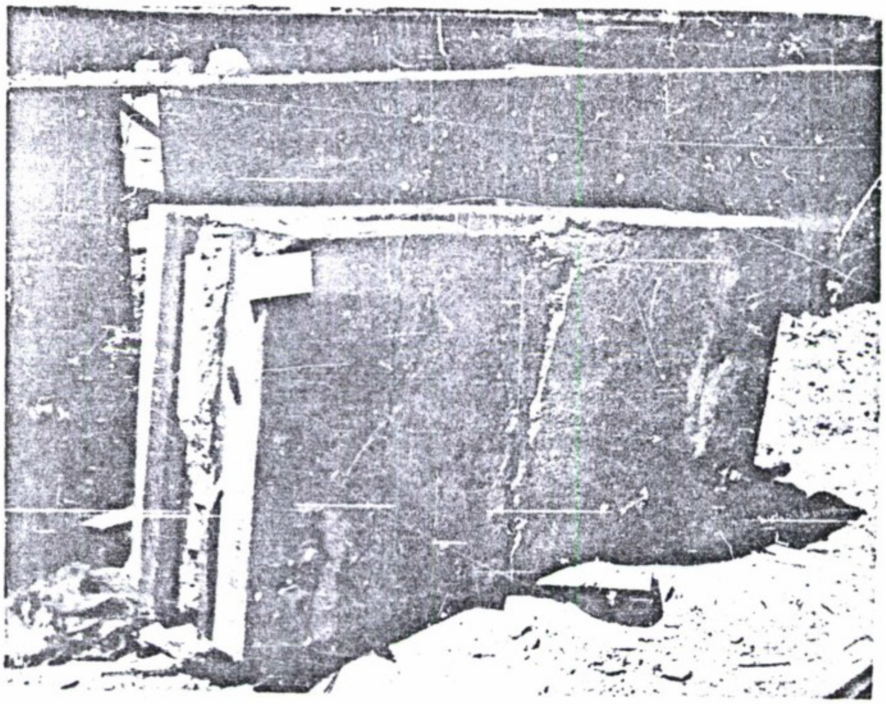
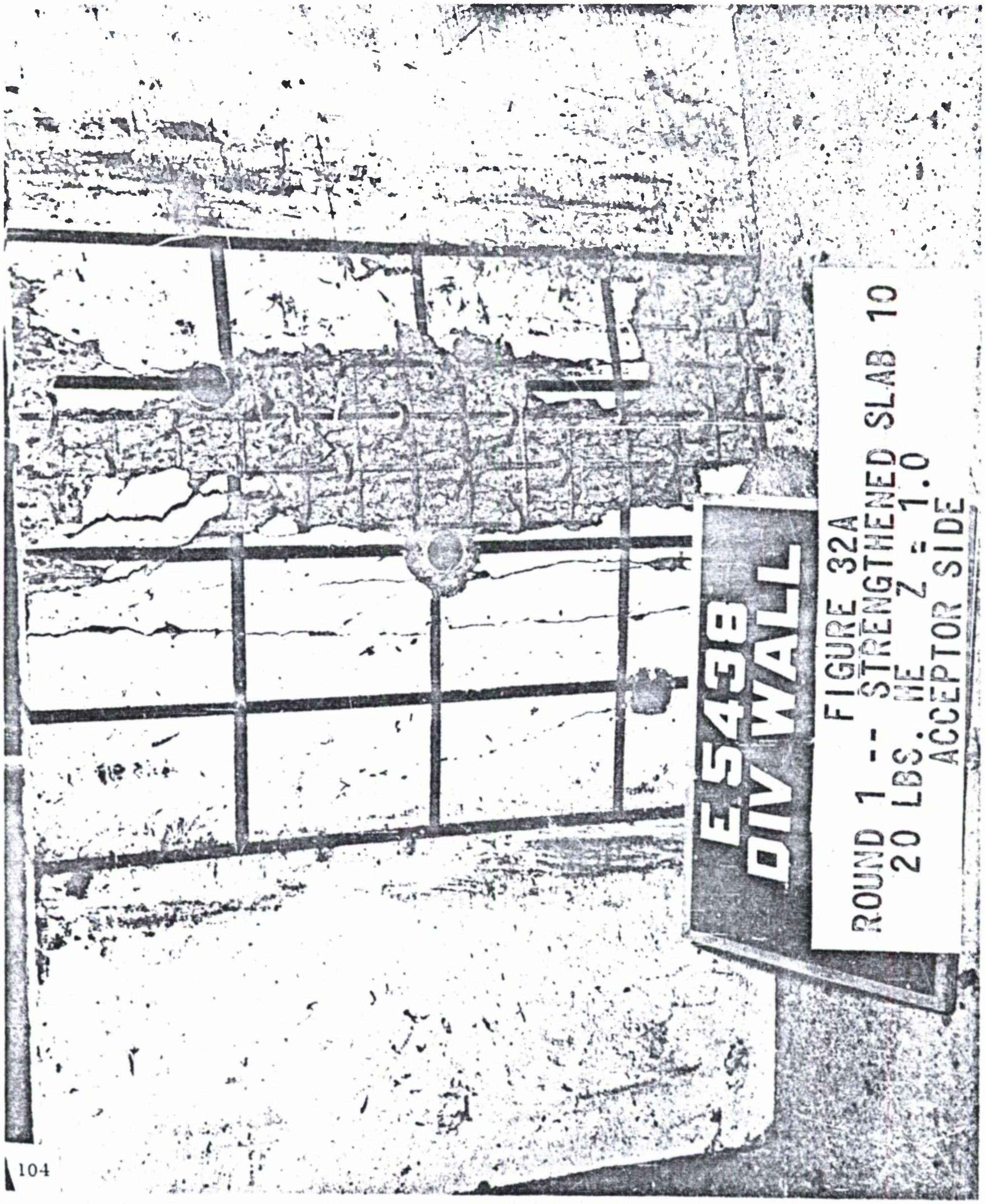


FIGURE 31
ROUND 17-1 -- COMPOSITE SLAB 8
30 LBS. HE Z = 0.5


E 5438
DIV WALL
FIGURE 32A
ROUND 1 -- STRENGTHENED SLAB 10
20 LBS. HE Z = 1.0
ACCEPTOR SIDE

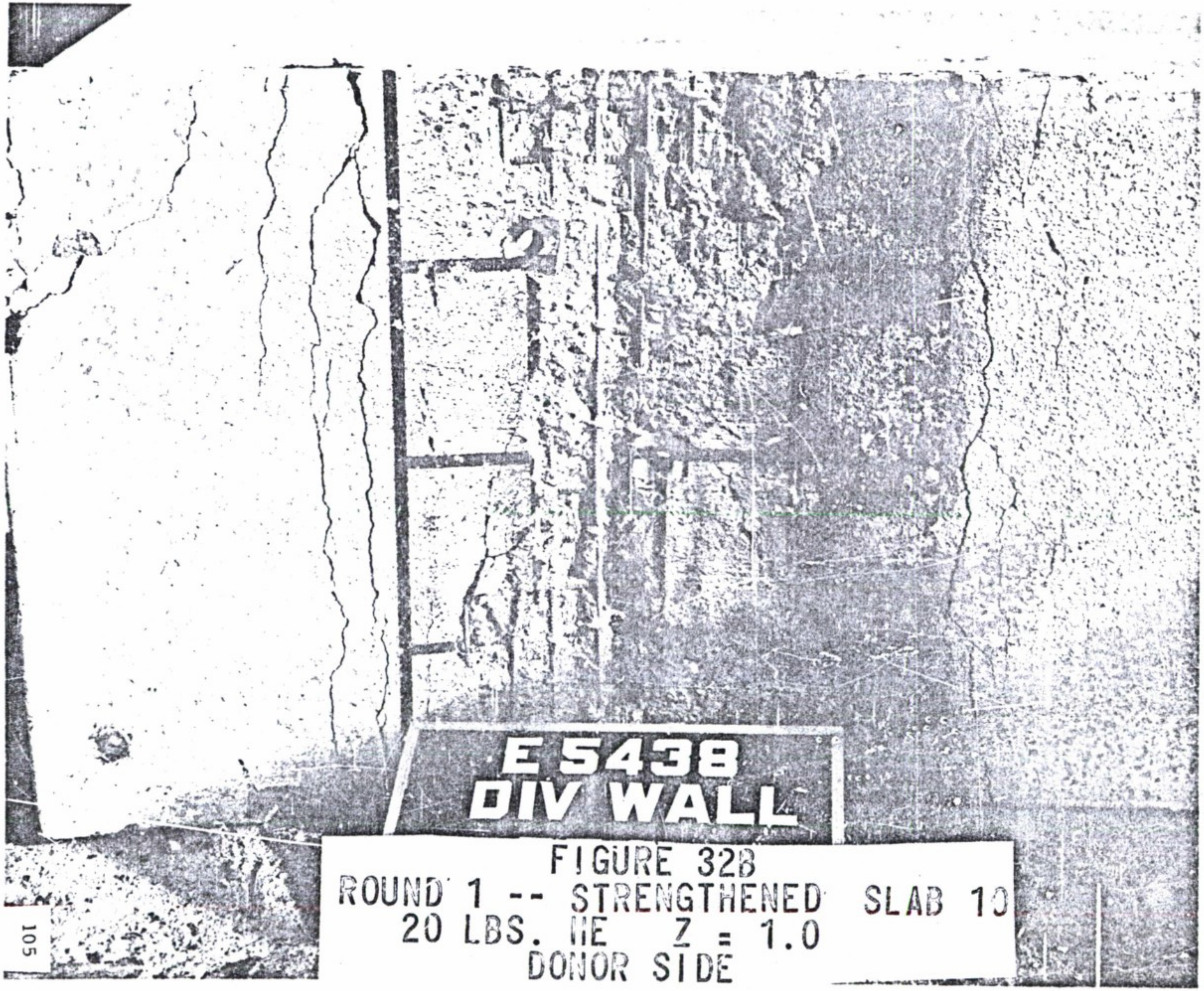


FIGURE 32B
ROUND 1 -- STRENGTHENED SLAB 10
20 LBS. HE $\bar{Z}$ = 1.0
DONOR SIDE

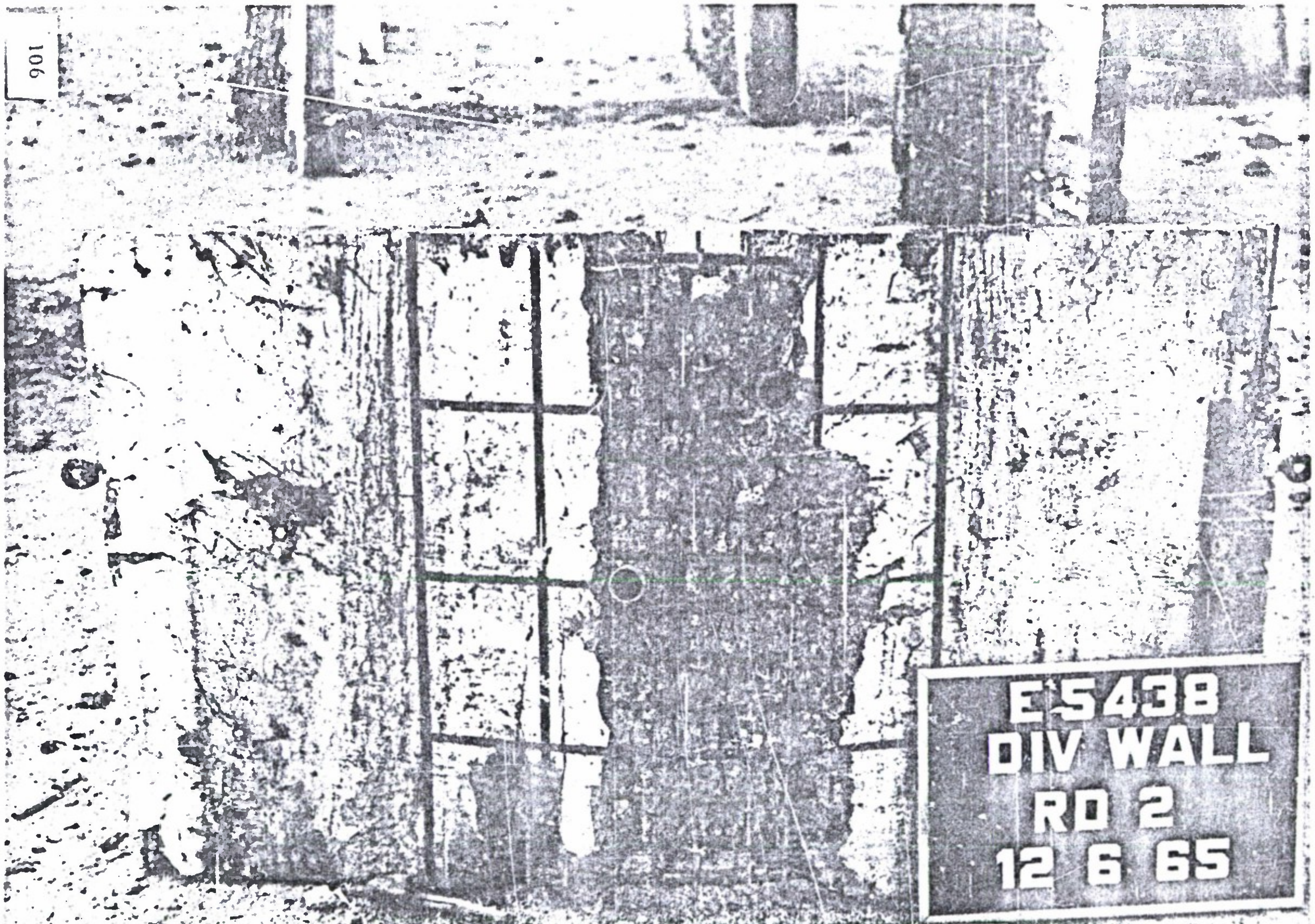


FIGURE 33A
ROUND 2 -- STRENGTHENED SLAB 10
20 LBS. HE Z = 0.8
ACCEPTOR SIDE

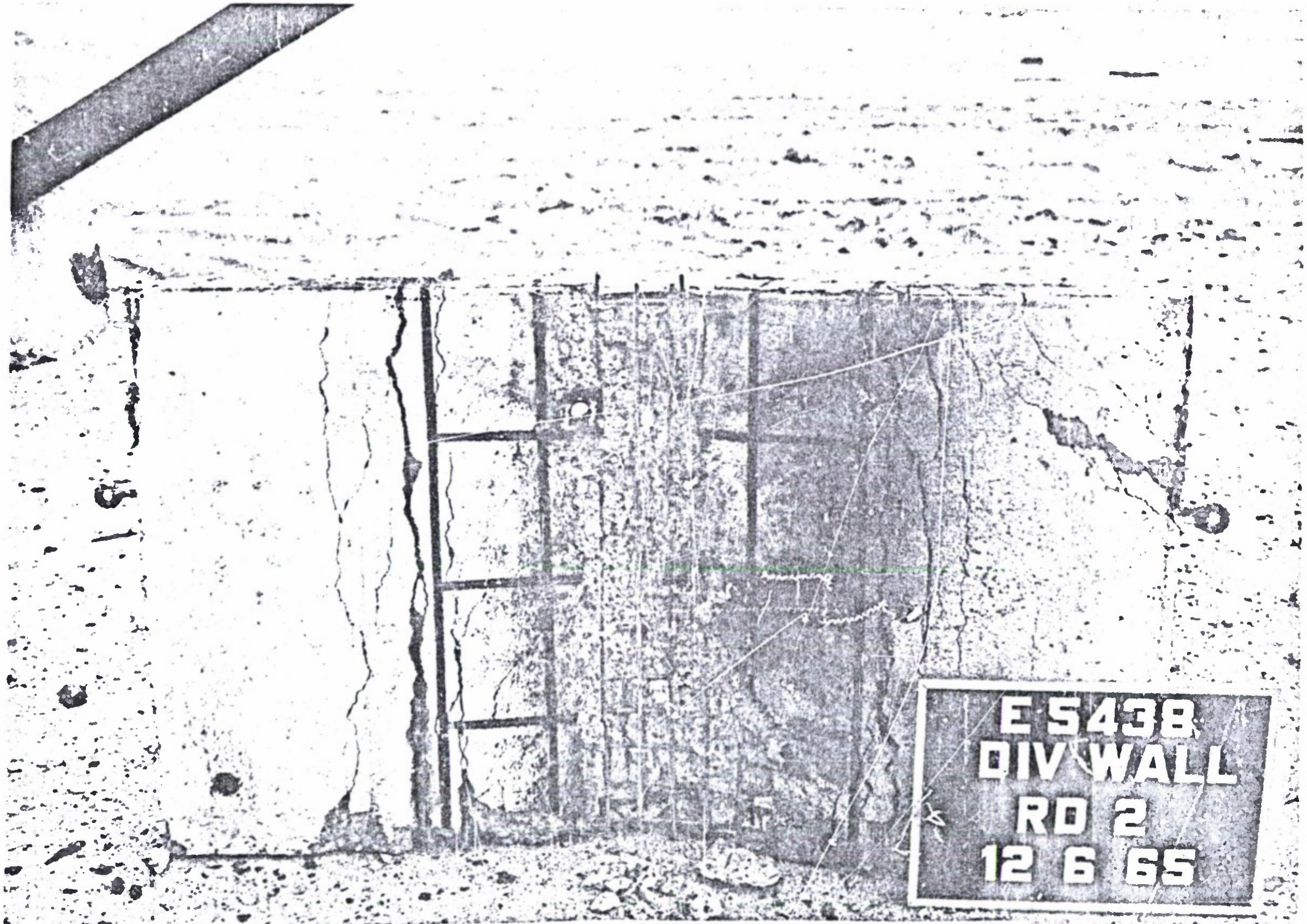


FIGURE 33B
ROUND 2 -- STRENGTHENED SLAB 10
20 LBS. HE Z = 0.8
DONOR SIDE

FIGURE 34A
ROUND 3 -- STRENGTHENED SLAB 11
20 LBS HE Z = 0.8
ACCEPTOR SIDE

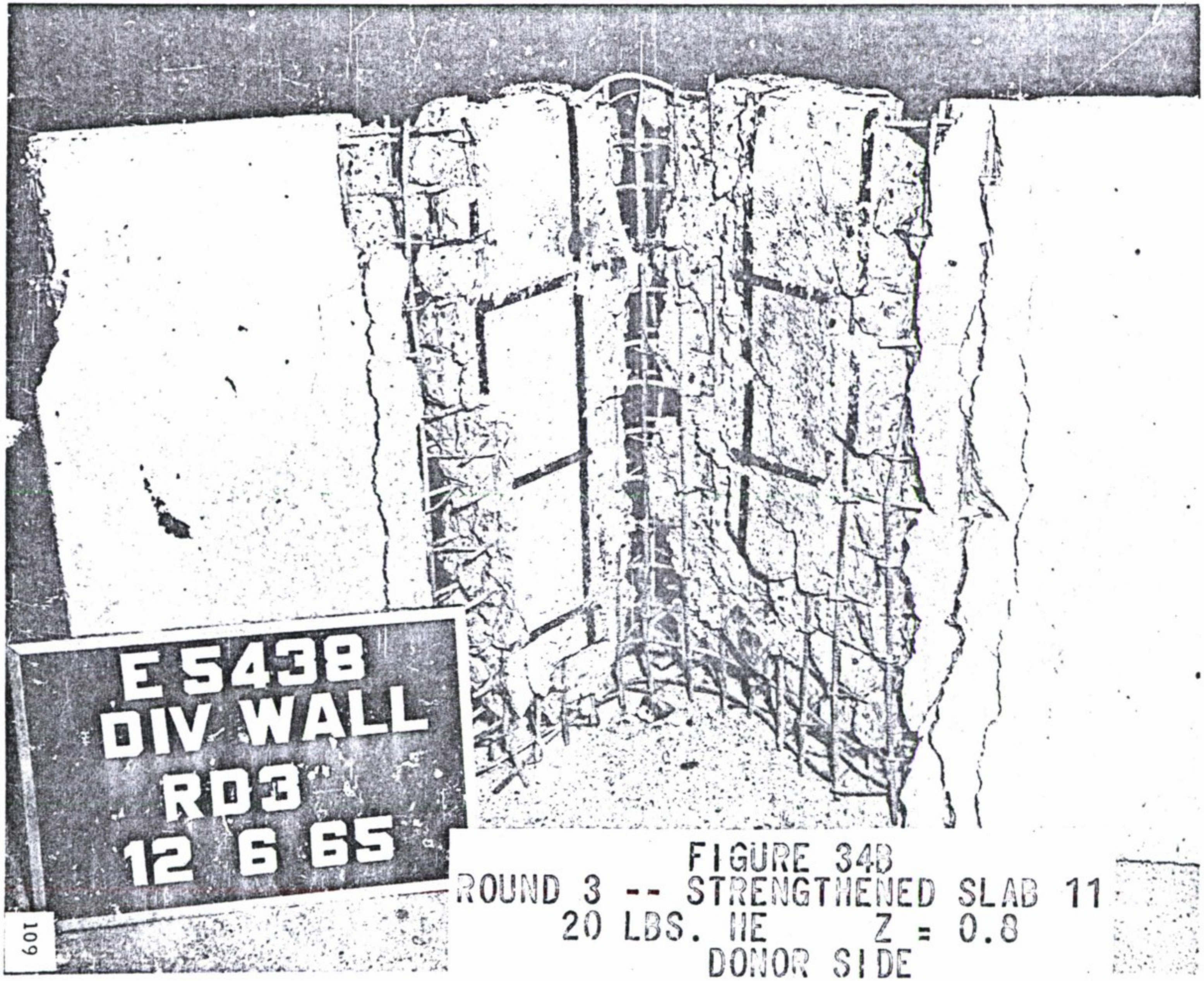


FIGURE 34B
ROUND 3 -- STRENGTHENED SLAB 11
20 LBS. HE Z = 0.8
DONOR SIDE

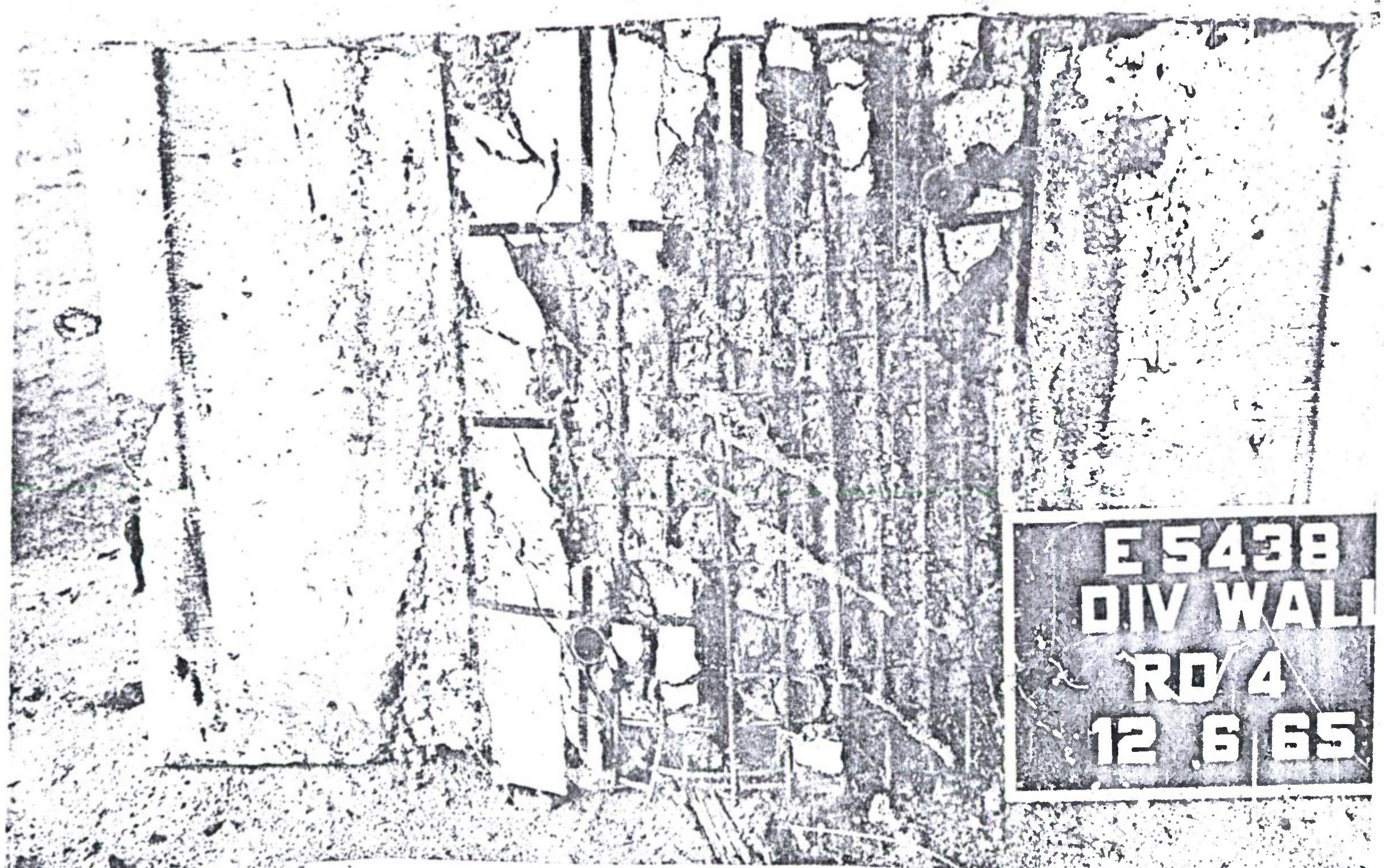


FIGURE 35A
ROUND 4 -- STRENGTHENED SLAB 11
20 LBS. HE   Z = 1.0
ACCEPTOR SIDE

FIGURE 35B
ROUND 4 -- STRENGTHENED SLAB 1
20 LBS. HE Z = 1.0
END VIEW

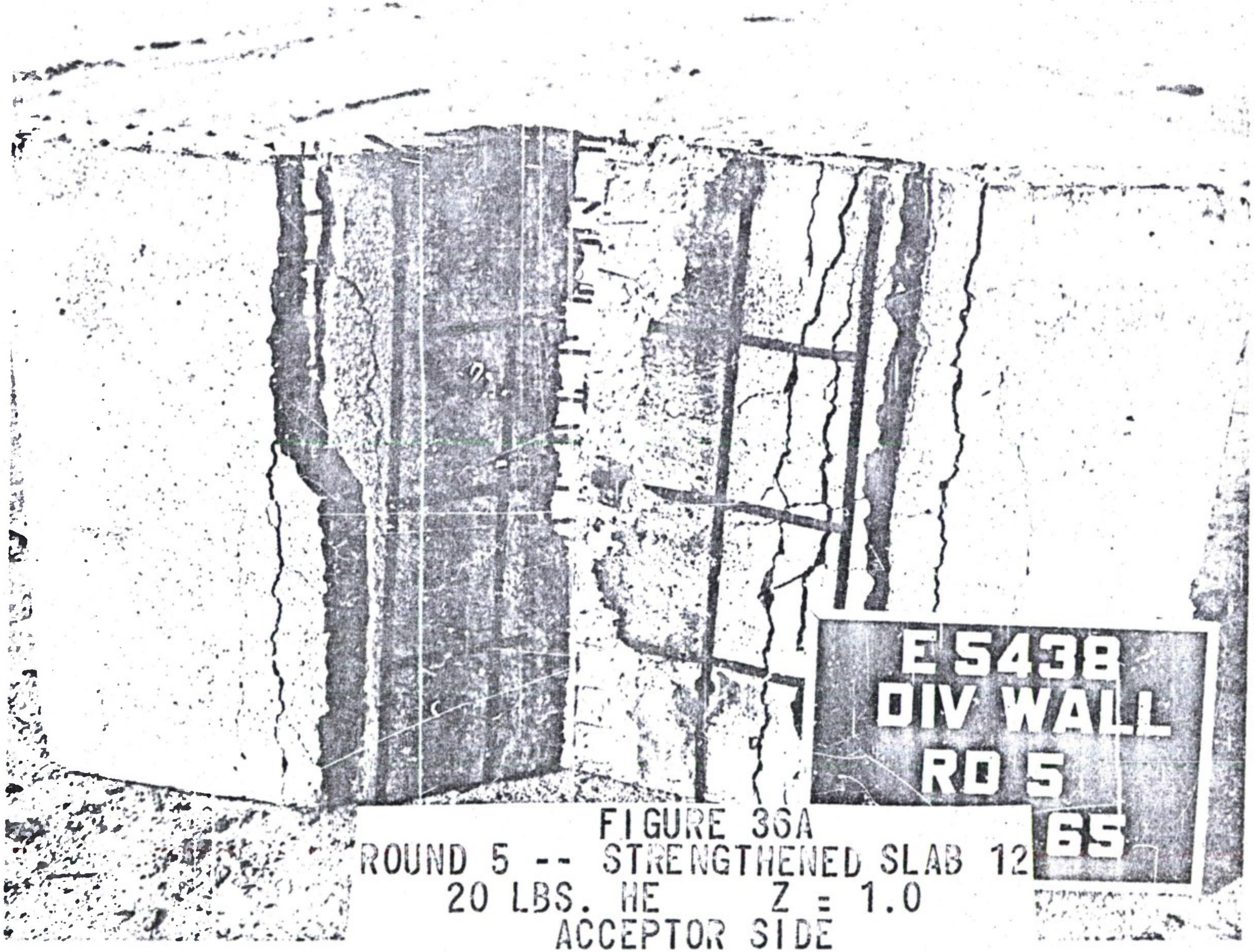


FIGURE 36A
ROUND 5 -- STRENGTHENED SLAB 12
20 LBS. HE Z = 1.0
ACCEPTOR SIDE

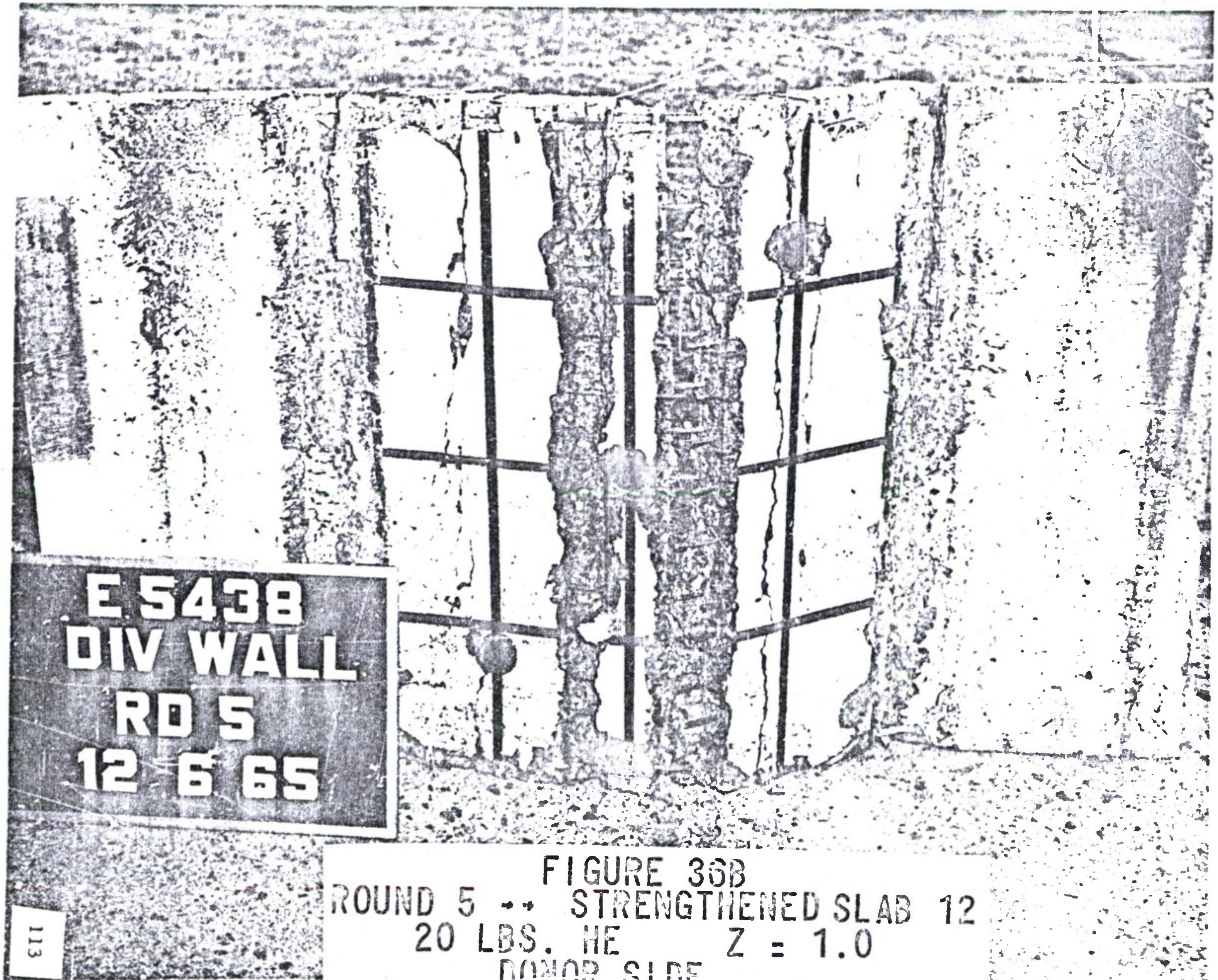


FIGURE 36B
ROUND 5 -- STRENGTHENED SLAB 12
20 LBS. HE Z = 1.0
DONOR SIDE

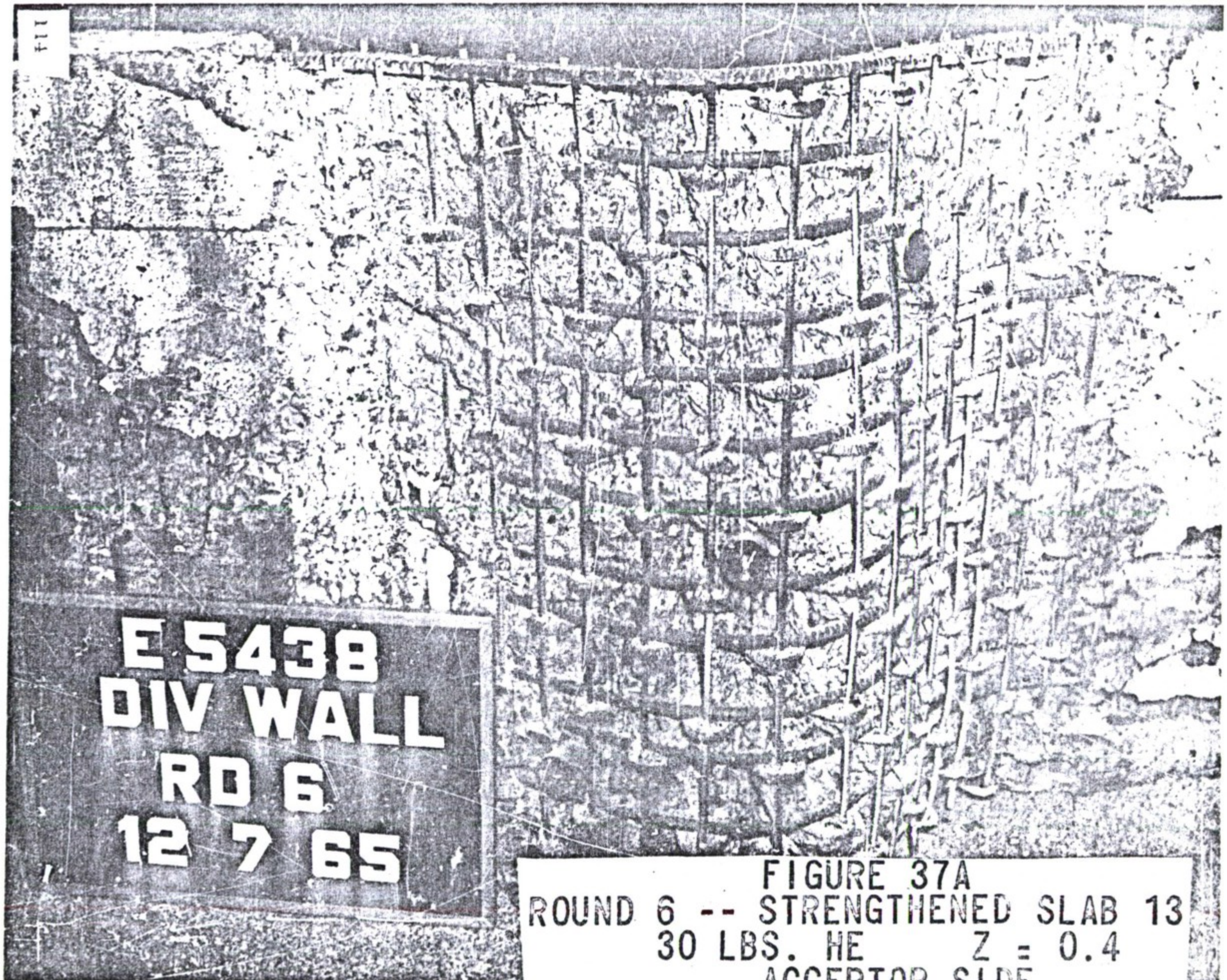


FIGURE 37A
ROUND 6 -- STRENGTHENED SLAB 13
30 LBS. HE   Z = 0.4
ACCEPTOR SIDE

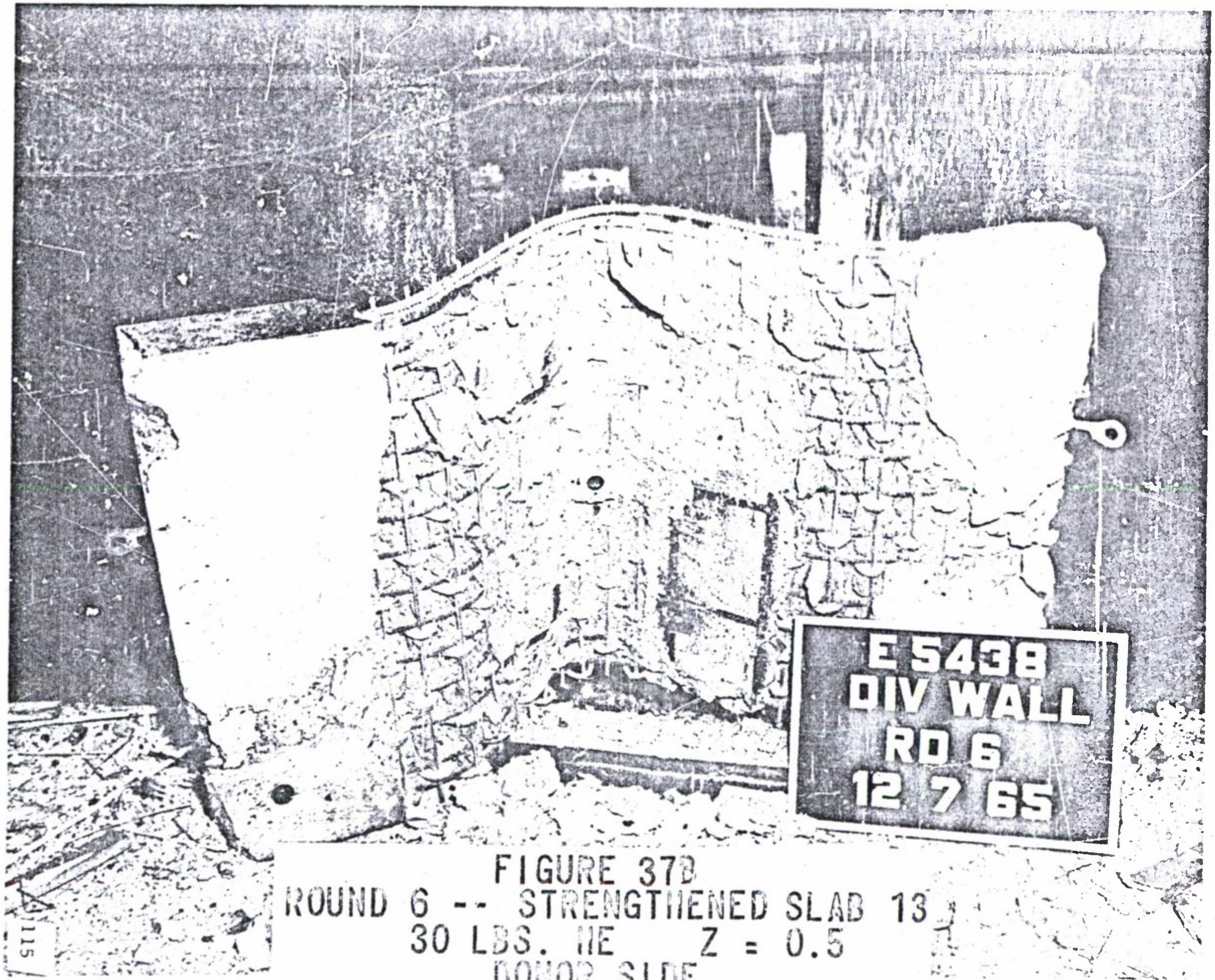


FIGURE 37B
ROUND 6 -- STRENGTHENED SLAB 13
30 LBS. HE Z = 0.5
DONOR SIDE

FIGURE 38A
ROUND 8 -- STRENGHTENED SLAB 13
30 LBS. HE Z = 0.5
TESTED AS BACK WALL OF CUBICLE
ACCEPTOR SIDE

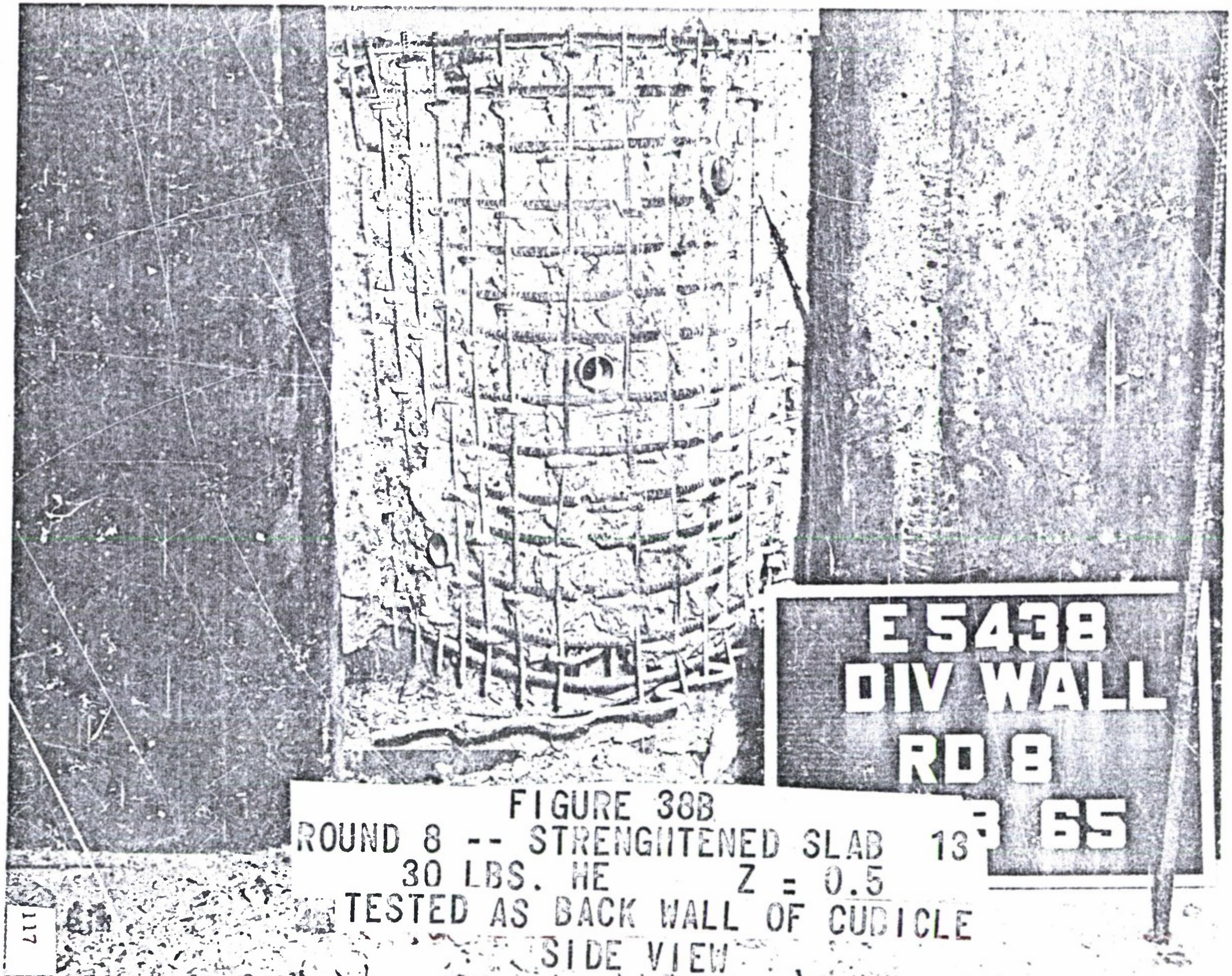


FIGURE 38B
ROUND 8 -- STRENGHTENED SLAB 13
30 LBS. HE Z = 0.5
TESTED AS BACK WALL OF CUBICLE
SIDE VIEW

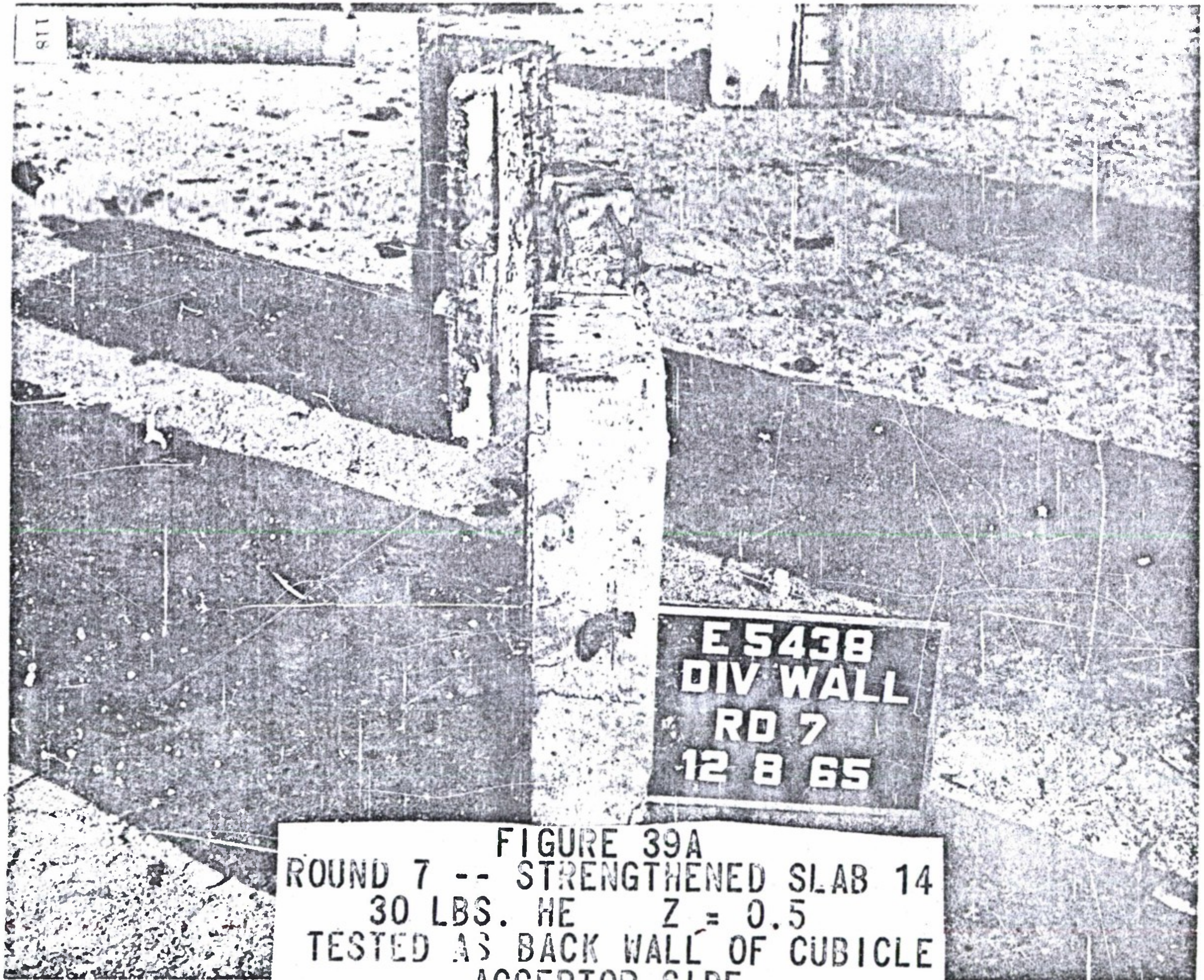


FIGURE 39A
ROUND 7 -- STRENGTHENED SLAB 14
30 LBS. HE   Z = 0.5
TESTED AS BACK WALL OF CUBICLE
ACCEPTOR SIDE

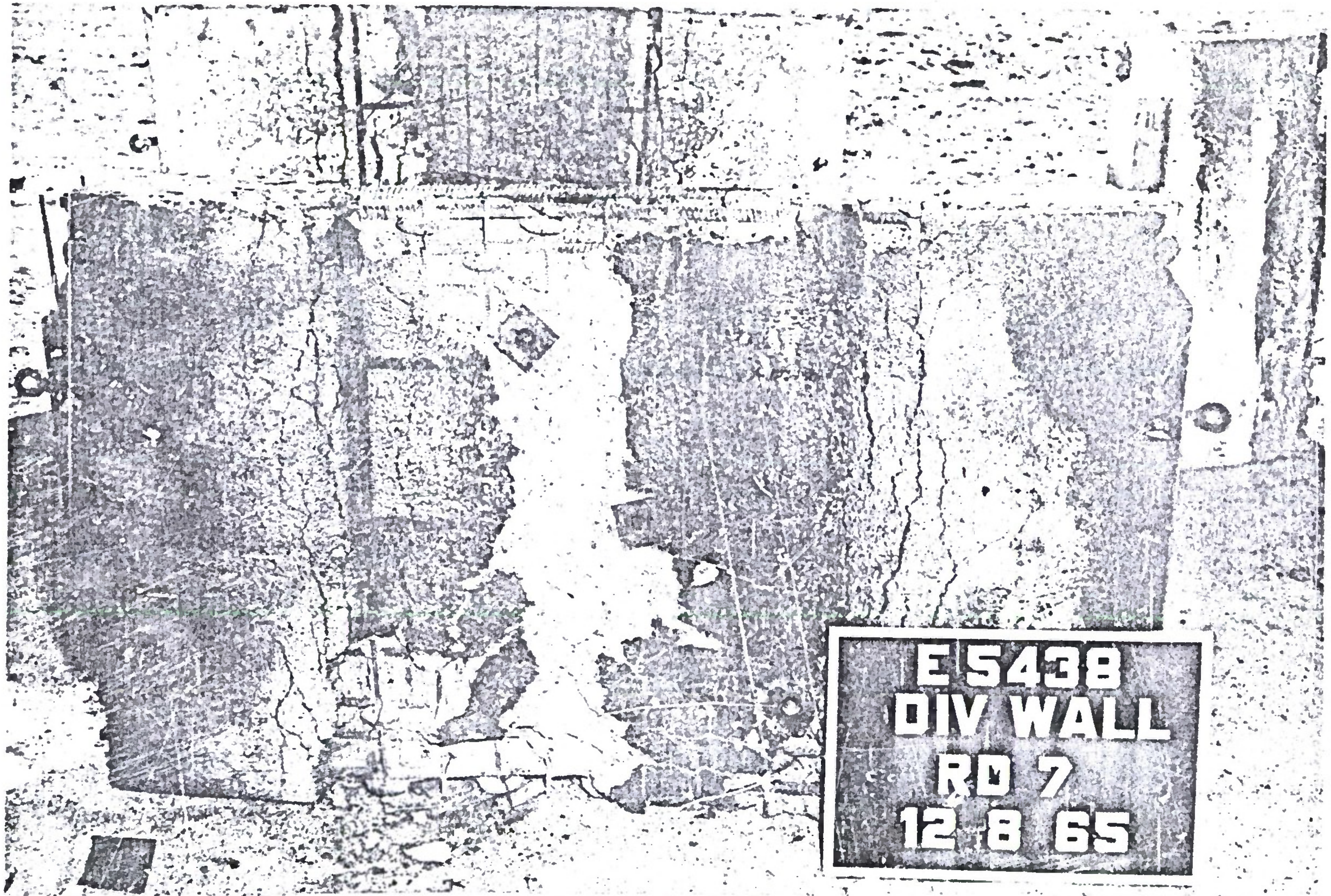


FIGURE 39B
ROUND 7 -- STRENGTHENED SLAB 14
30 LBS. HE Z = 0.5
TESTED AS BACK WALL OF CUBICLE
SIDE VIEW

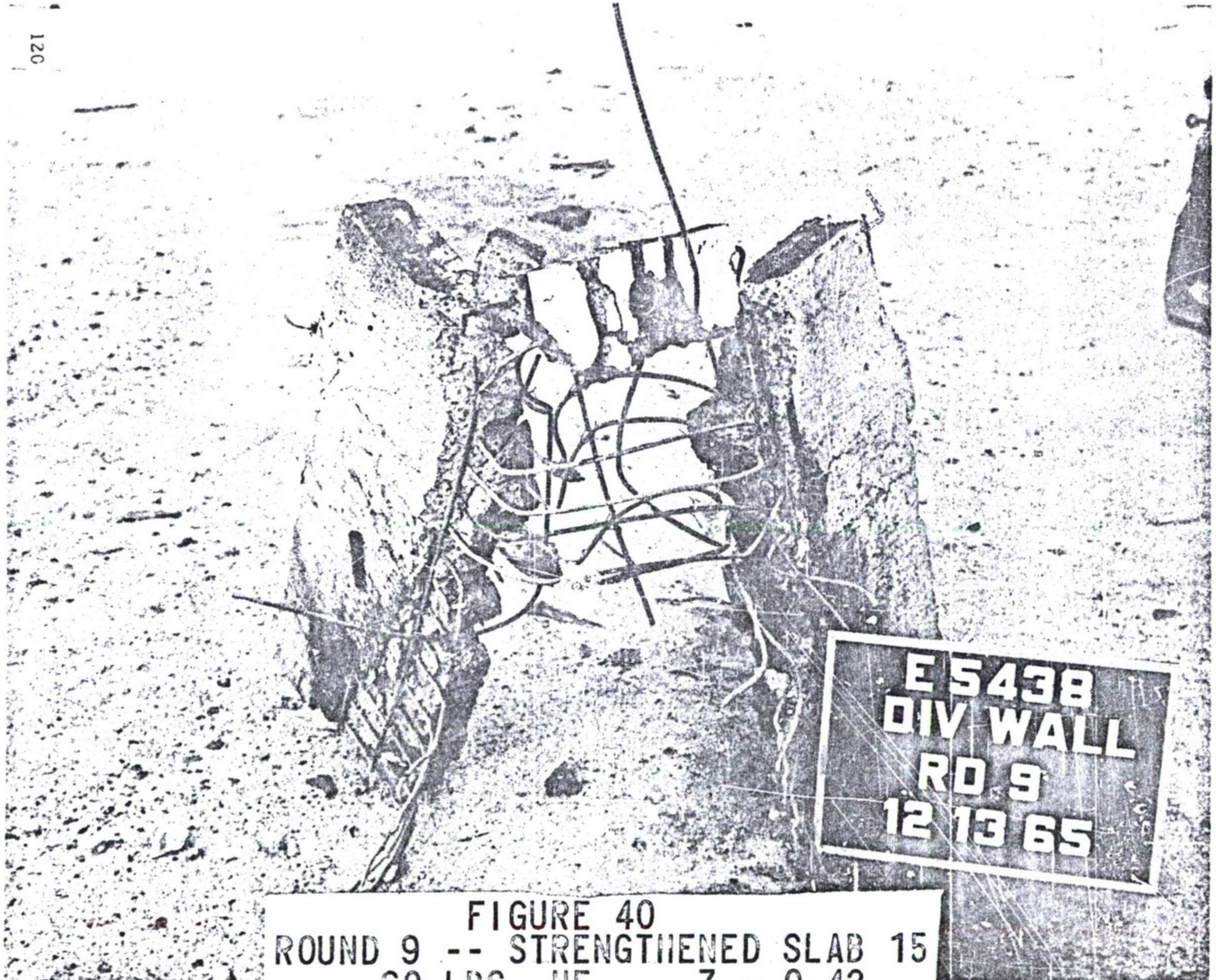


FIGURE 40
ROUND 9 -- STRENGTHENED SLAB 15
60 LBS. HE Z = 0.42

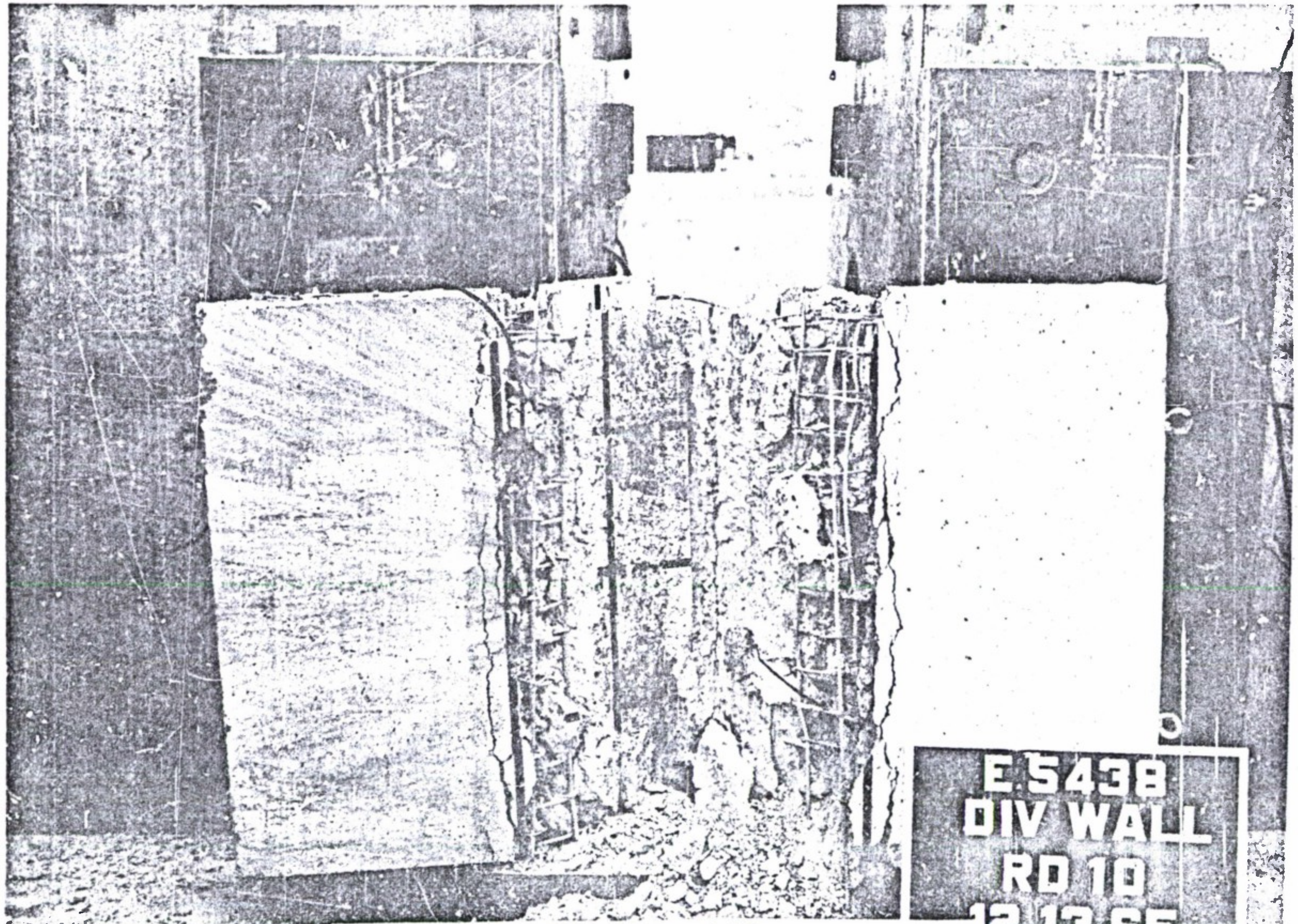


FIGURE 41A
ROUND 10 -- COMPOSITE SLAB 9
40 LBS. HE   Z = 0.5
DONOR SIDE

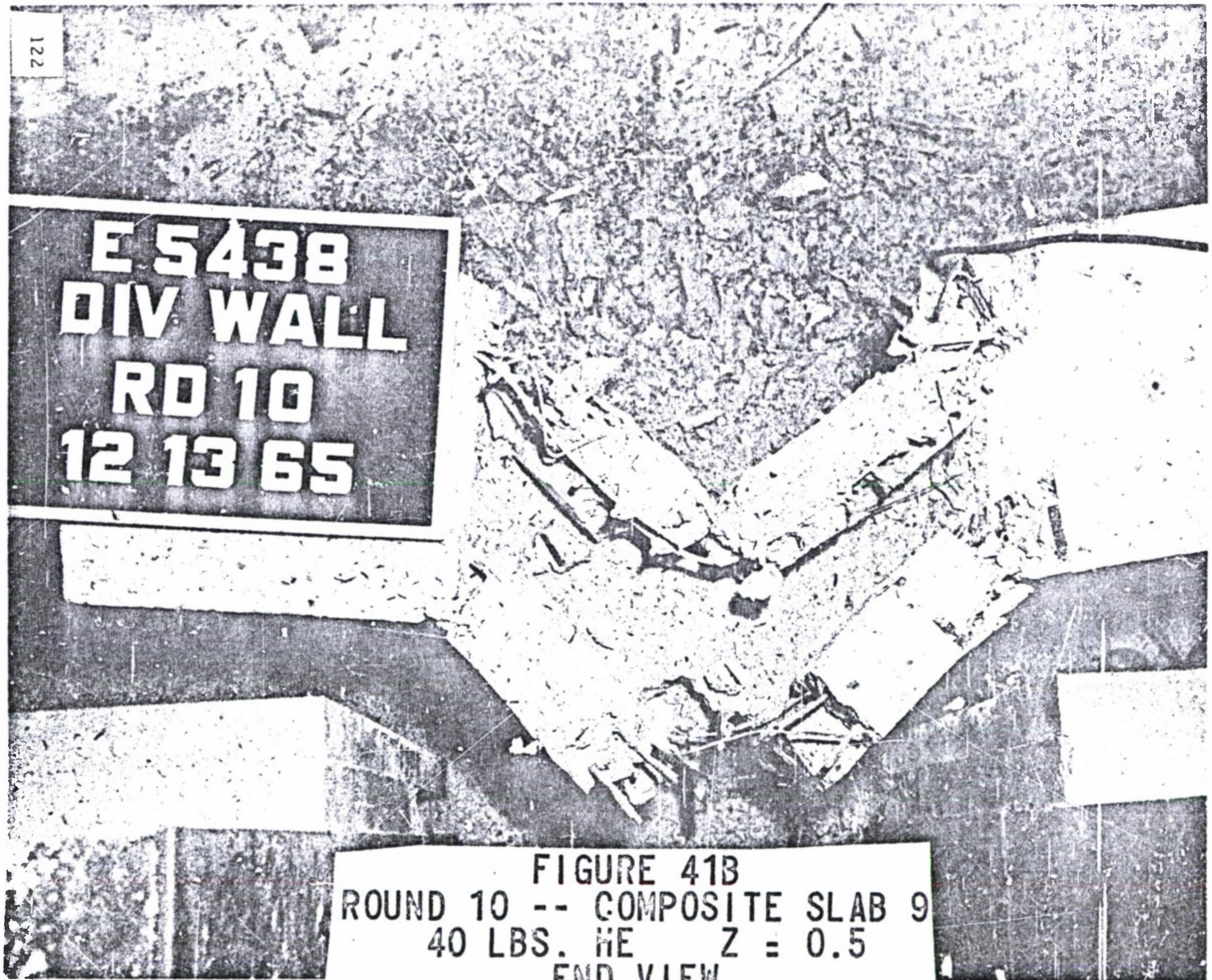


FIGURE 41B
ROUND 10 -- COMPOSITE SLAB 9
40 LBS. HE Z = 0.5
END VIEW

FIGURE 42A
ROUND 11 -- COMPOSITE SLAB 9
30 LBS. HE   Z = 0.5
END VIEW

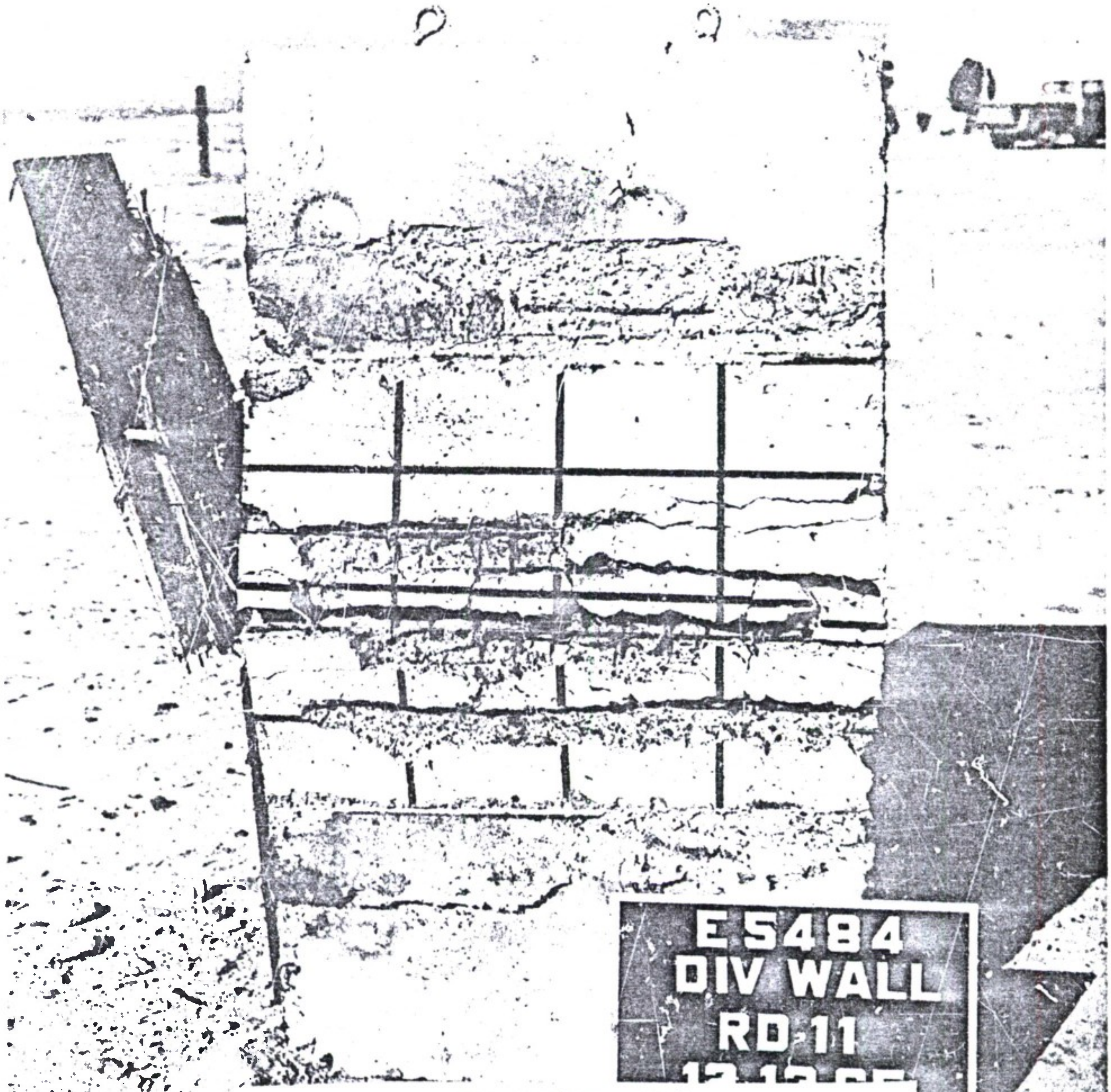


FIGURE 42B
ROUND 11 -- COMPOSITE SLAB 9
30 LBS. HE Z = 0.5
ACCEPTOR SIDE

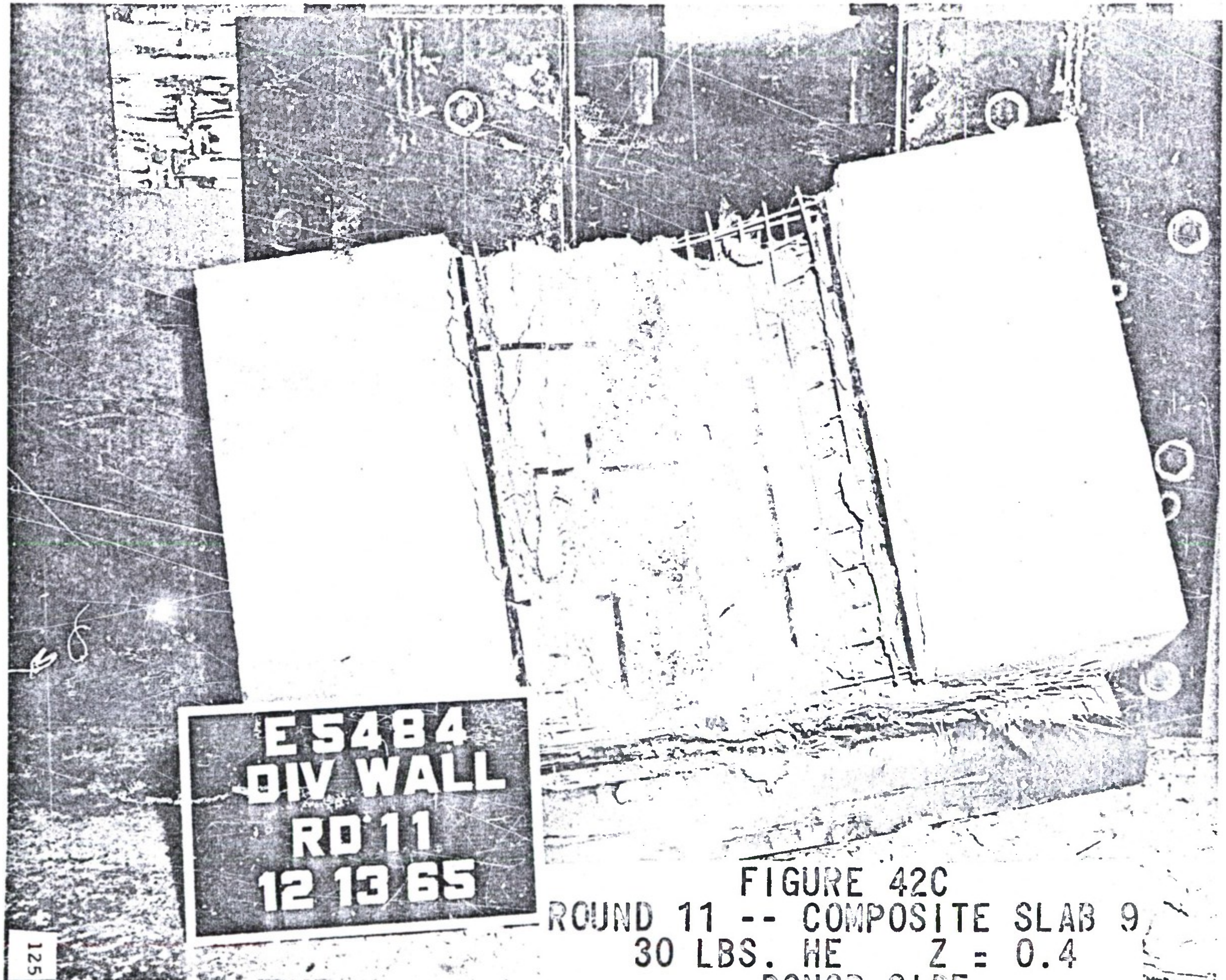


FIGURE 42C
ROUND 11 -- COMPOSITE SLAB 9
30 LBS. HE Z = 0.4
DONOR SIDE

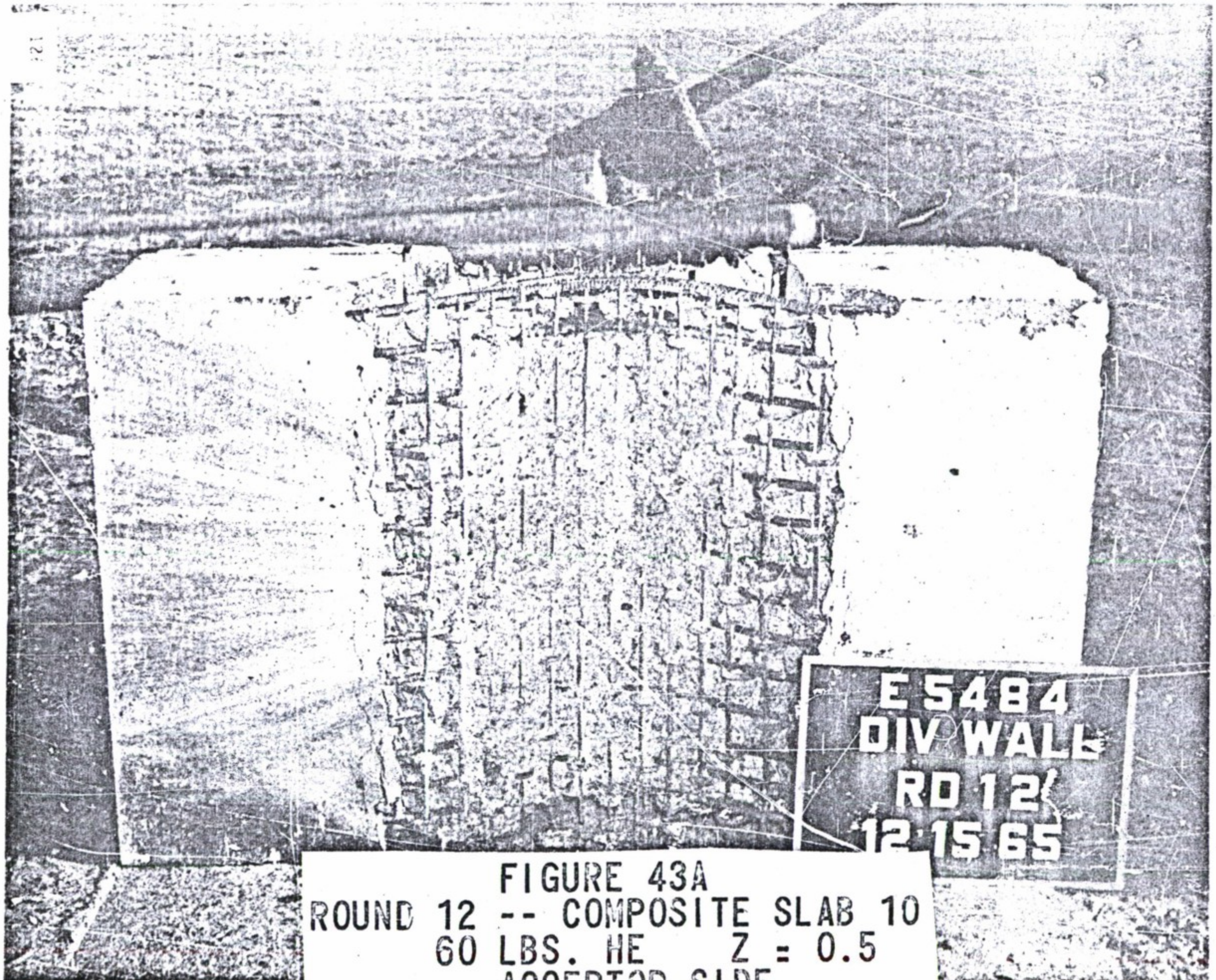


FIGURE 43A
ROUND 12 -- COMPOSITE SLAB 10
60 LBS. HE Z = 0.5
ACCEPTOR SIDE

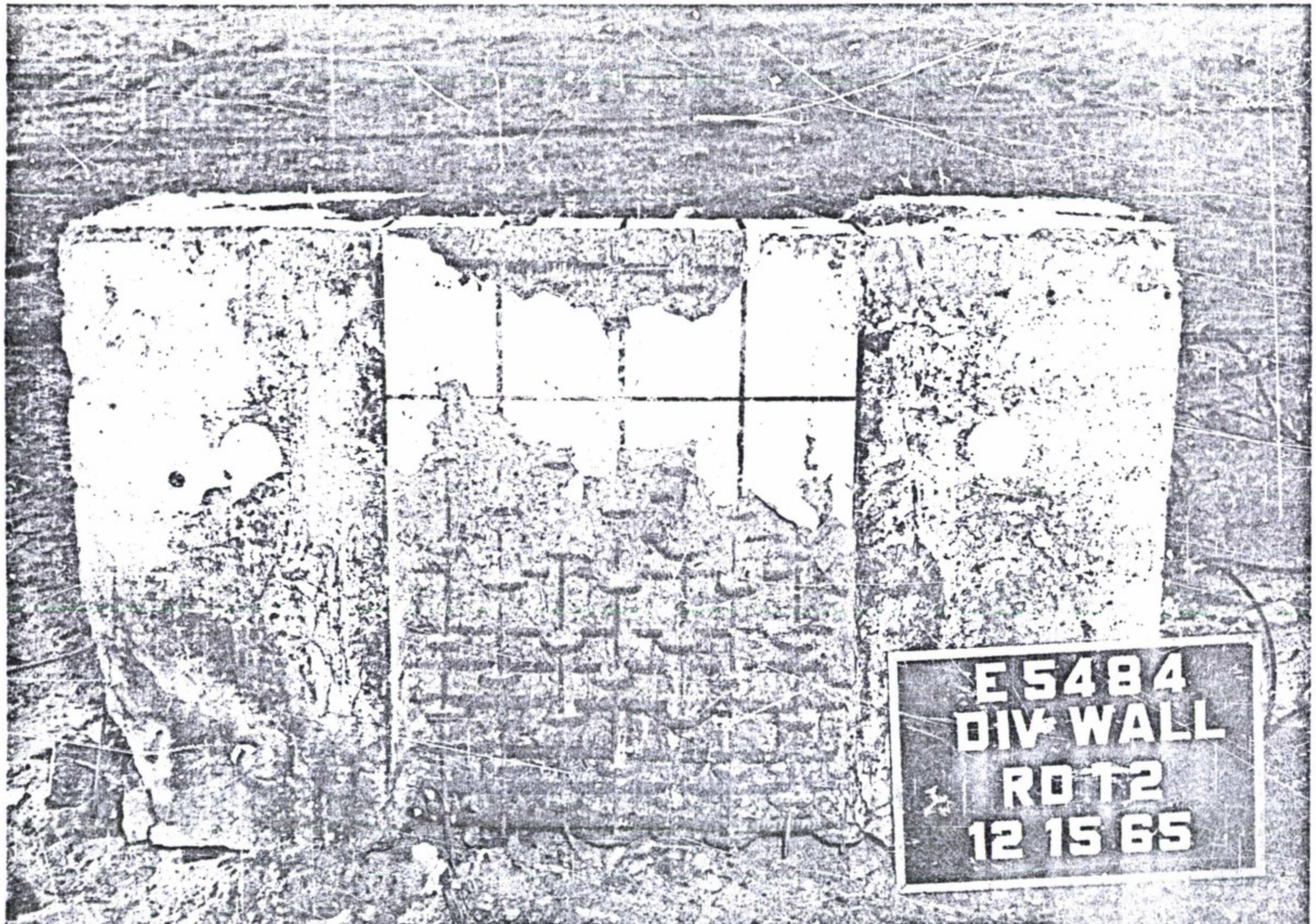


FIGURE 43B
ROUND 12 -- COMPOSITE SLAB 10
60 LBS. HE Z = 0.4
DONOR SIDE

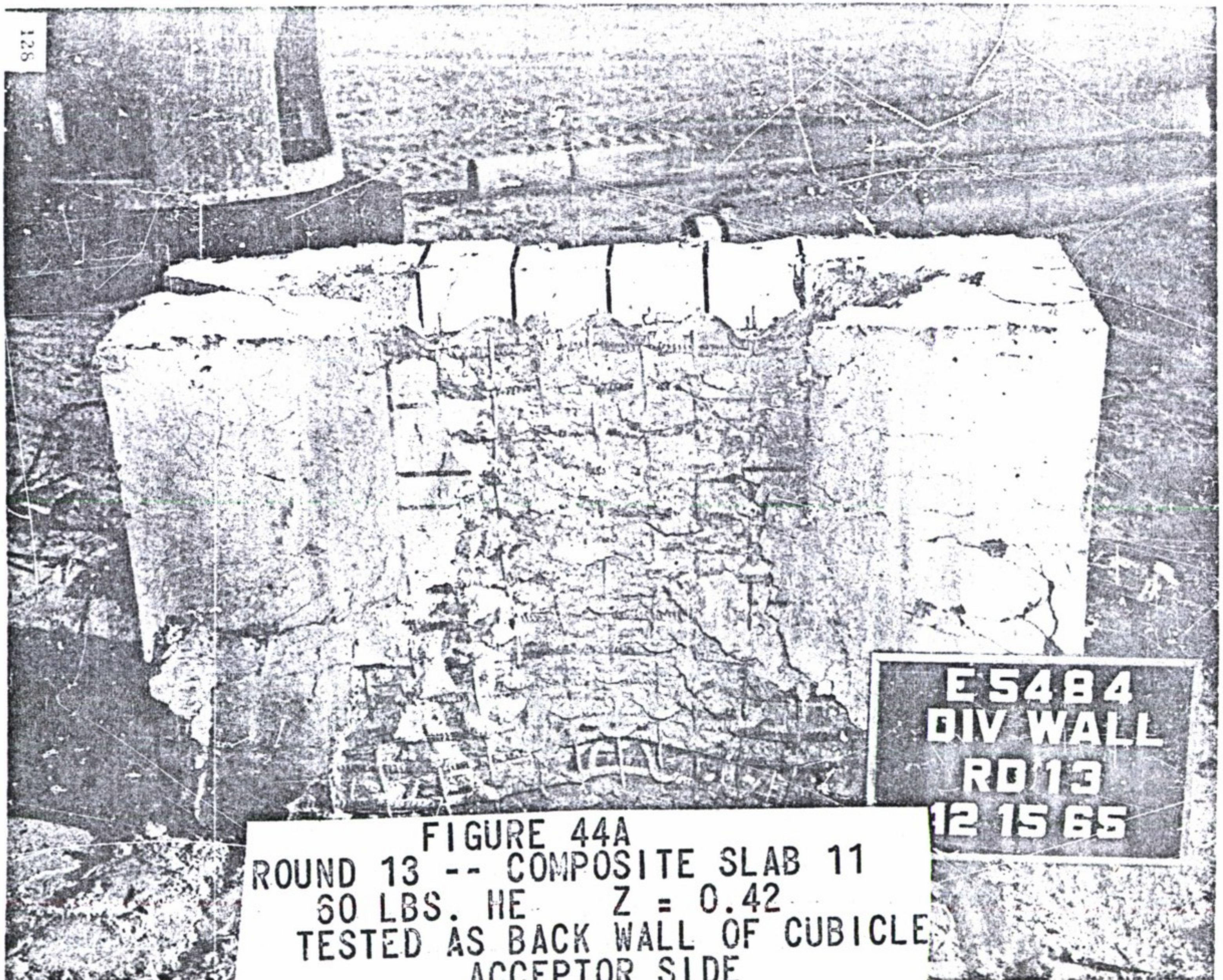


FIGURE 44A
ROUND 13 -- COMPOSITE SLAB 11
60 LBS. HE Z = 0.42
TESTED AS BACK WALL OF CUBICLE
ACCEPTOR SIDE

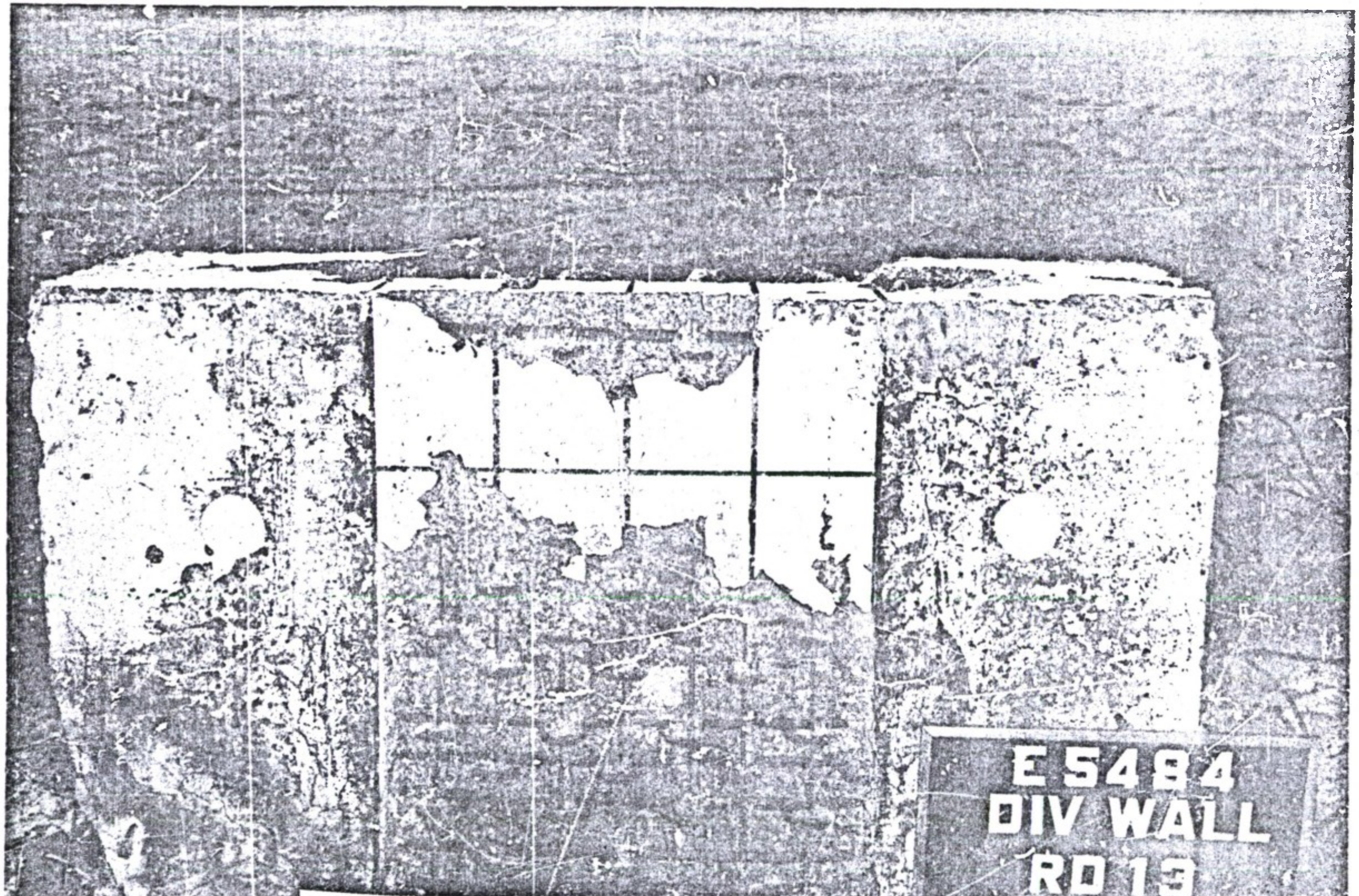


FIGURE 44B
ROUND 13 -- COMPOSITE SLAB 11
60 LBS. HE Z = 0.42
TESTED AS BACK WALL OF CUBICLE
DONOR SIDE

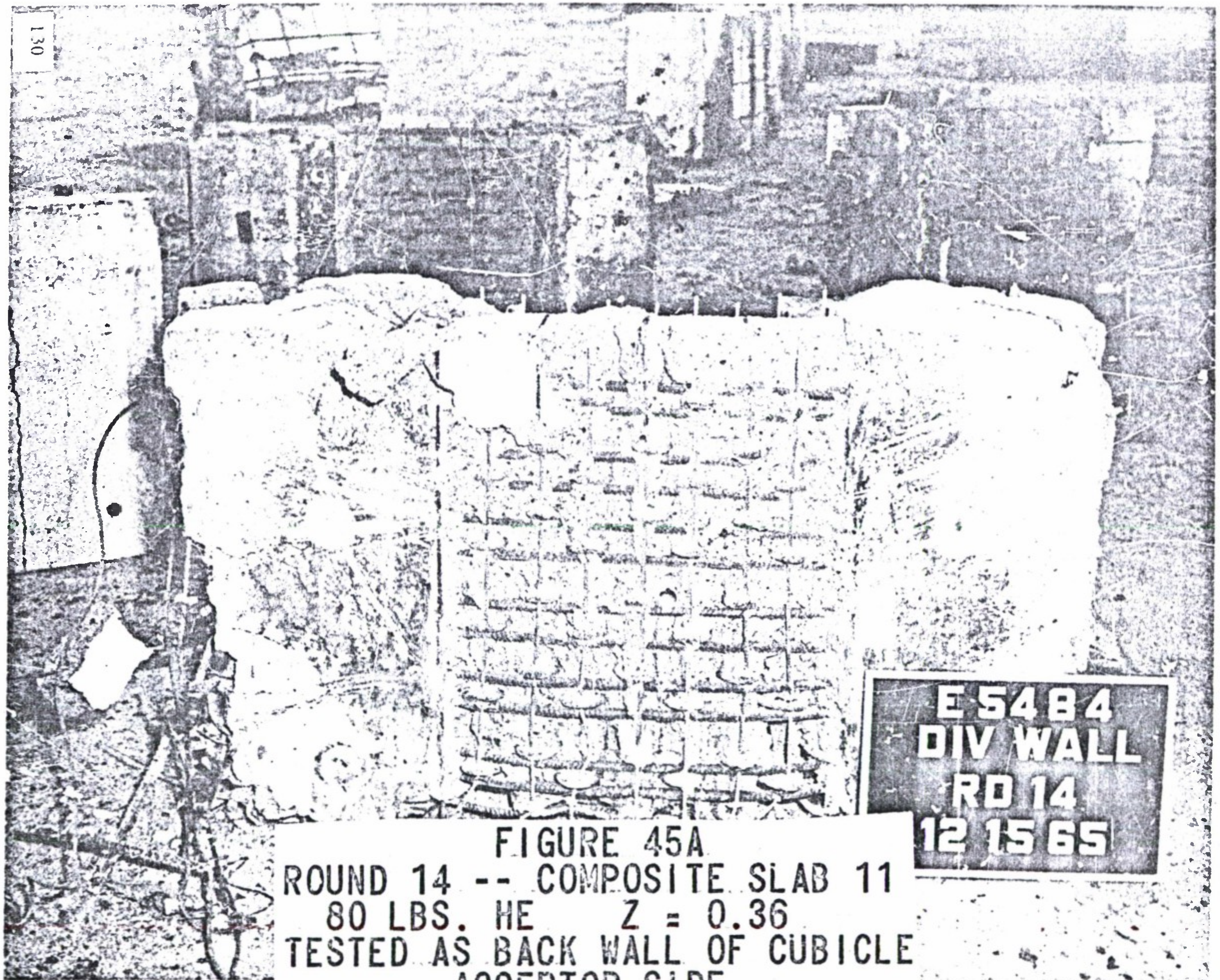


FIGURE 45A
ROUND 14 -- COMPOSITE SLAB 11
80 LBS. HE Z = 0.36
TESTED AS BACK WALL OF CUBICLE
ACCEPTOR SIDE

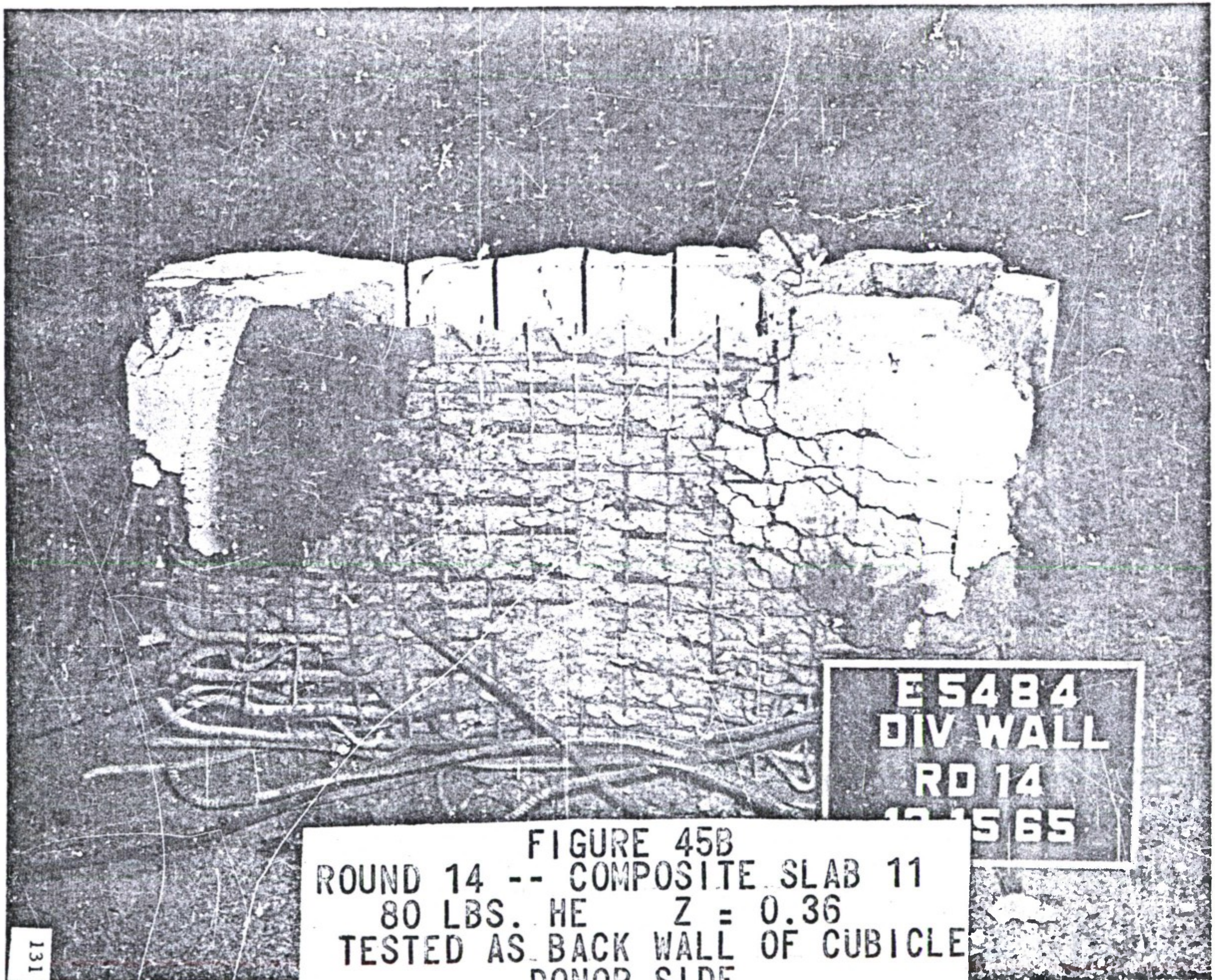


FIGURE 45B
ROUND 14 -- COMPOSITE SLAB 11
80 LBS. HE Z = 0.36
TESTED AS BACK WALL OF CUBICLE
DONOR SIDE

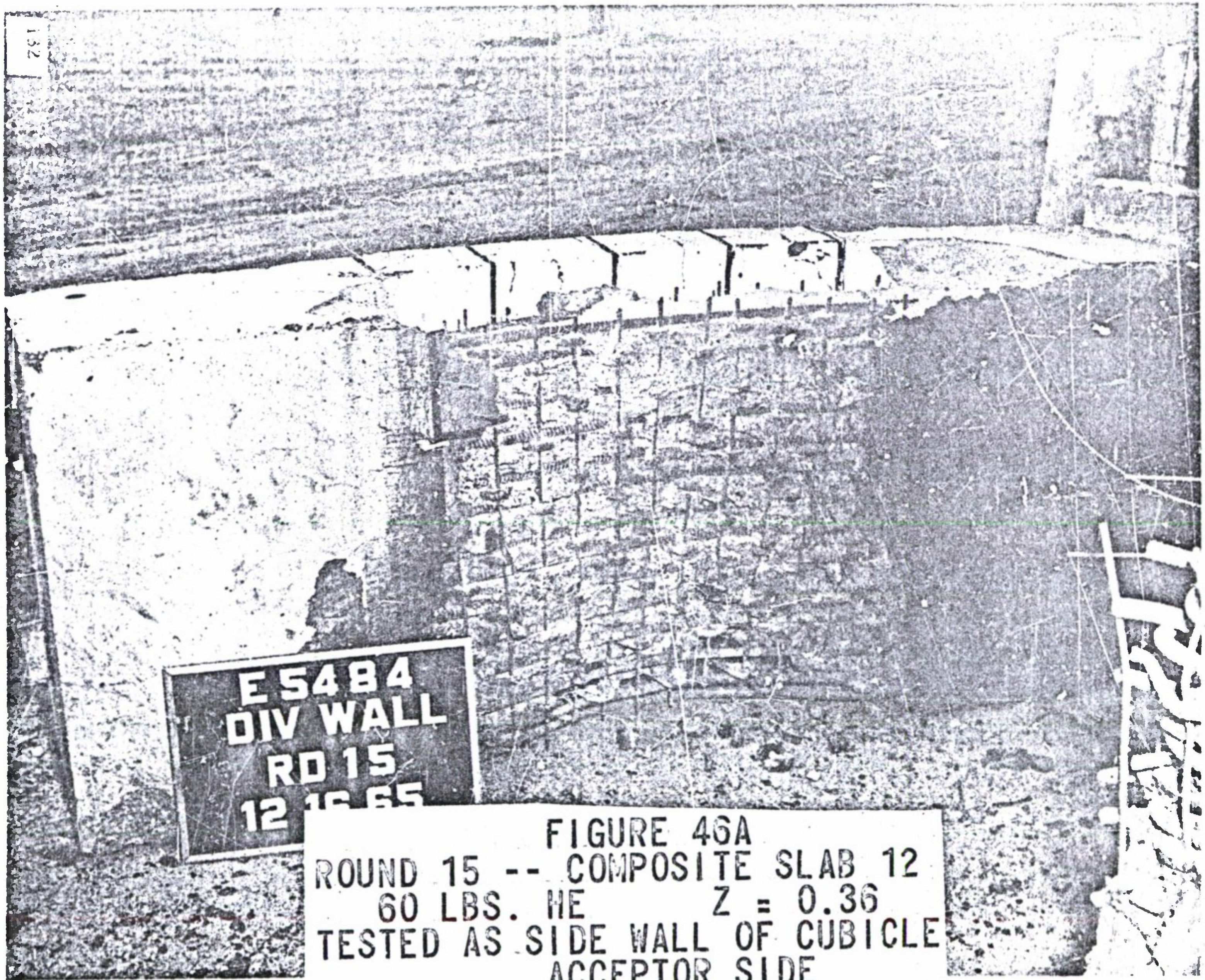


FIGURE 46A
ROUND 15 -- COMPOSITE SLAB 12
60 LBS. HE Z = 0.36
TESTED AS SIDE WALL OF CUBICLE
ACCEPTOR SIDE

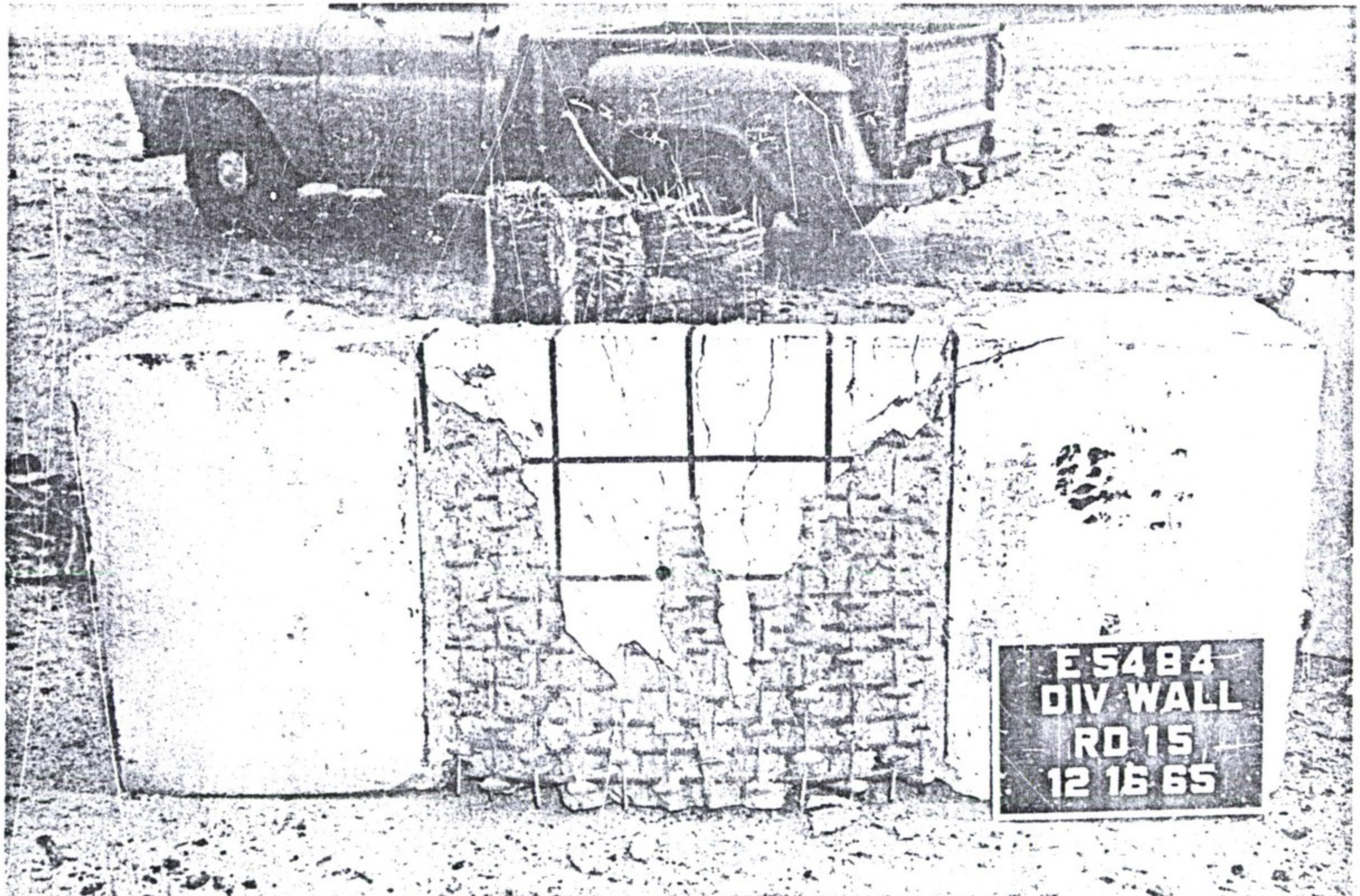


FIGURE 46B
ROUND 15 -- COMPOSITE SLAB 12
60 LBS. HE Z = 0.36
TESTED AS SIDE WALL OF CUBICLE
DONOR SIDE

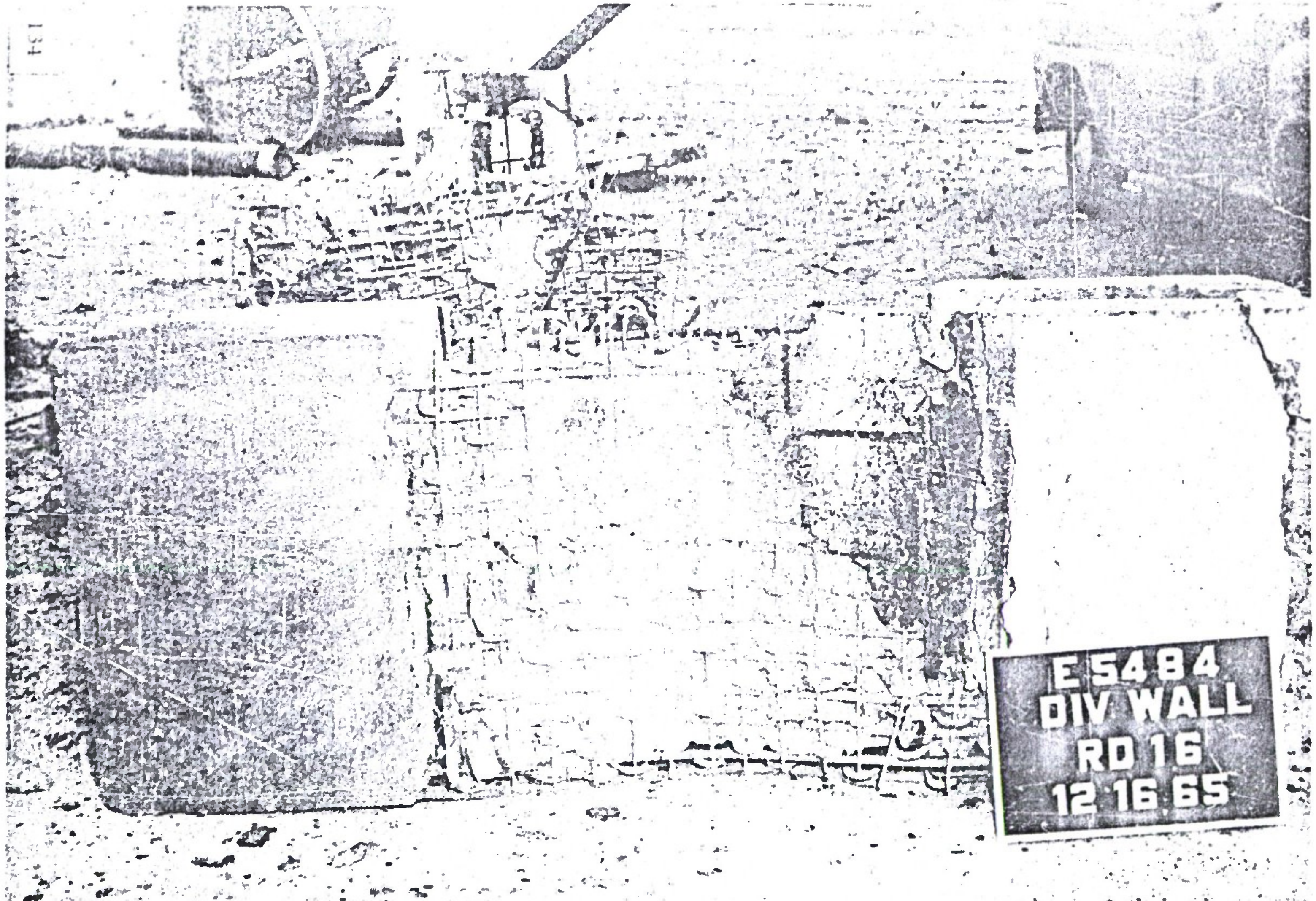


FIGURE 47A
ROUND 16 -- COMPOSITE SLAB 12
30 LBS. HE Z = 0.36
TESTED AS SIDE WALL OF CUBICLE
ACCEPTOR SIDE

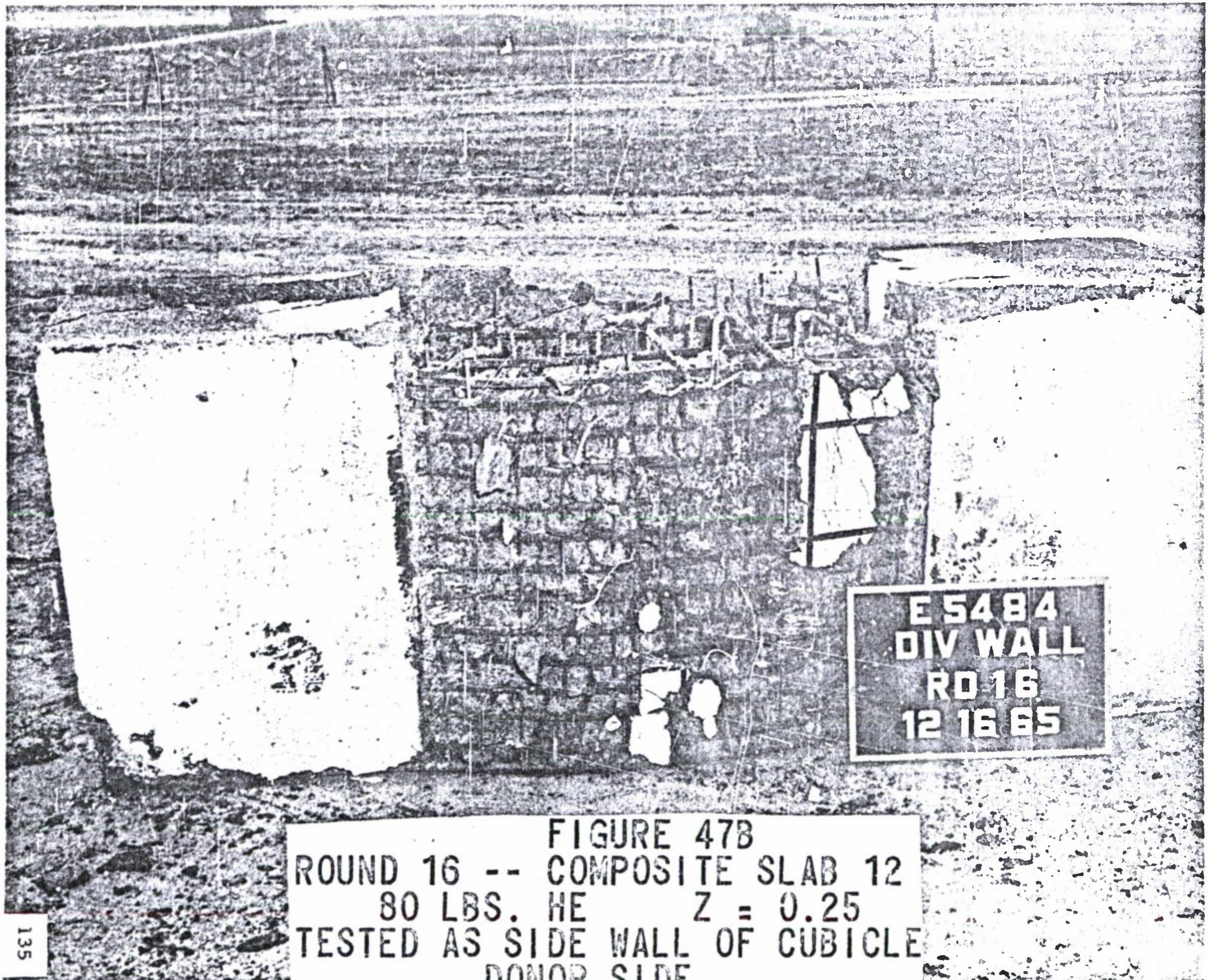


FIGURE 47B
ROUND 16 -- COMPOSITE SLAB 12
80 LBS. HE Z = 0.25
TESTED AS SIDE WALL OF CUBICLE
DONOR SIDE

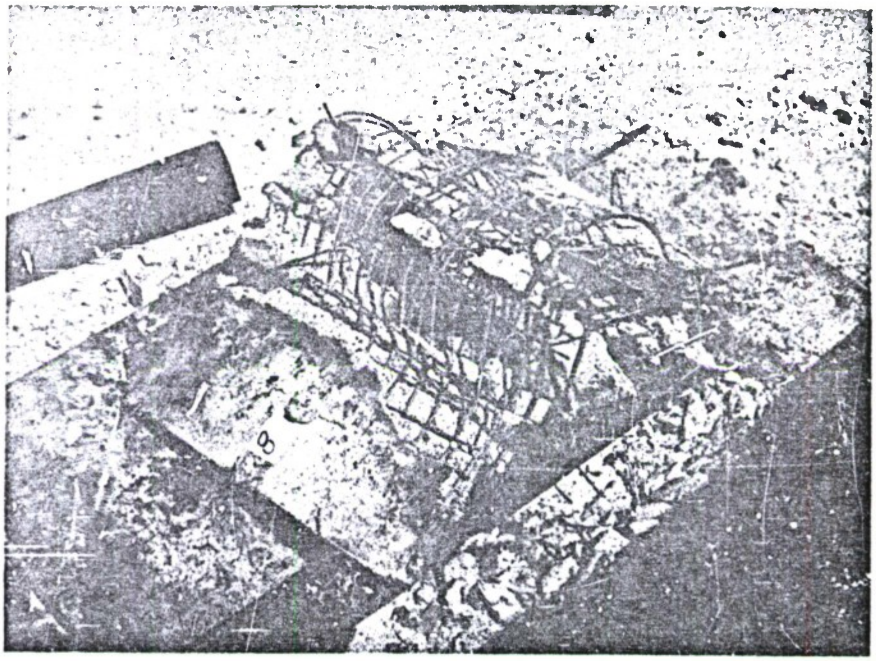


FIGURE 48
ROUND 1 -- STRENGTHENED SLAB 4
20 LBS. HE Z = 1.25
TESTED AS BACK WALL OF CUBICLE

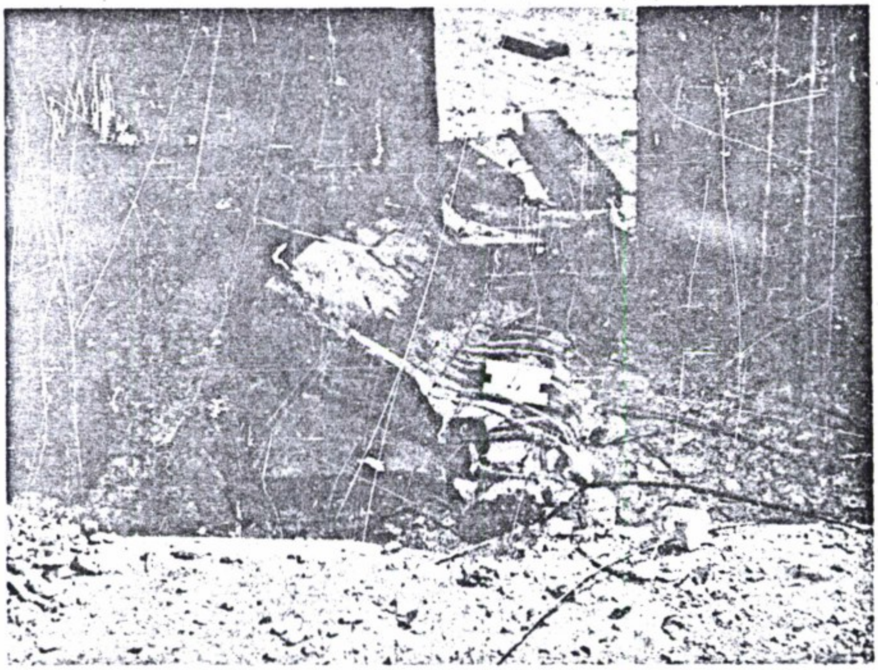


FIGURE 49
ROUND 2 -- STRENGTHENED SLAB 4
20 LBS. HE Z = 1.25
TESTED AS BACK WALL OF CUBICLE

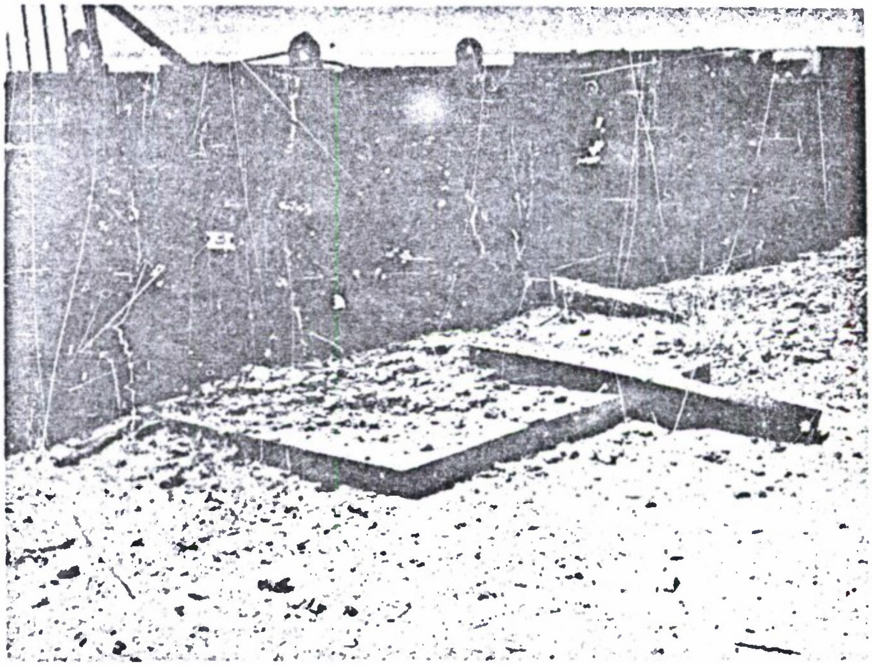


FIGURE 50
ROUND 3 -- STRENGTHENED SLAB 4
20 LBS. HE Z = 0.55
TESTED AS BACK WALL OF CUBICLE

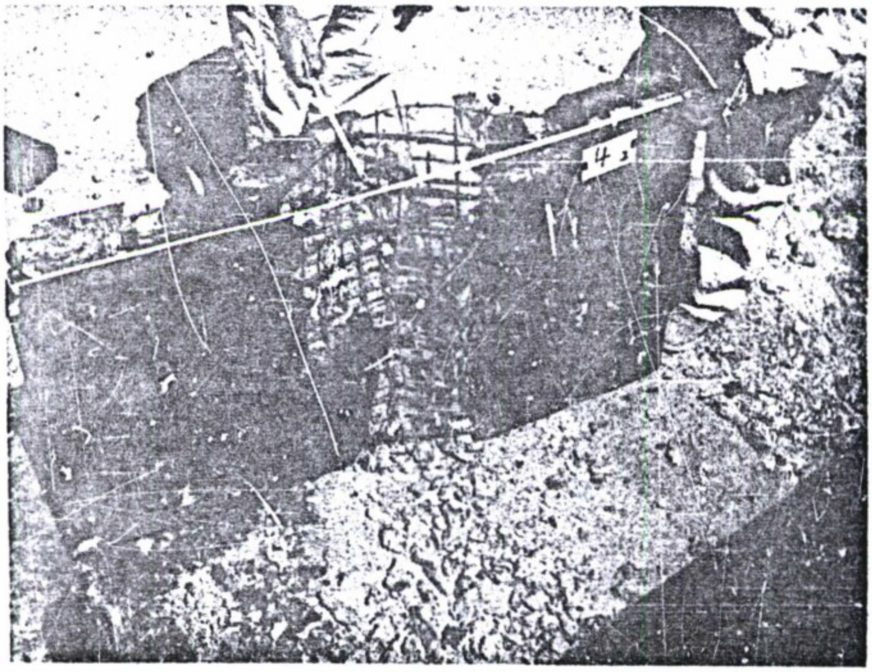


FIGURE 51
ROUND 4 -- STRENGTHENED SLAB 4
20 LBS. HE Z = 1.6
TESTED AS BACK WALL OF CUBICLE

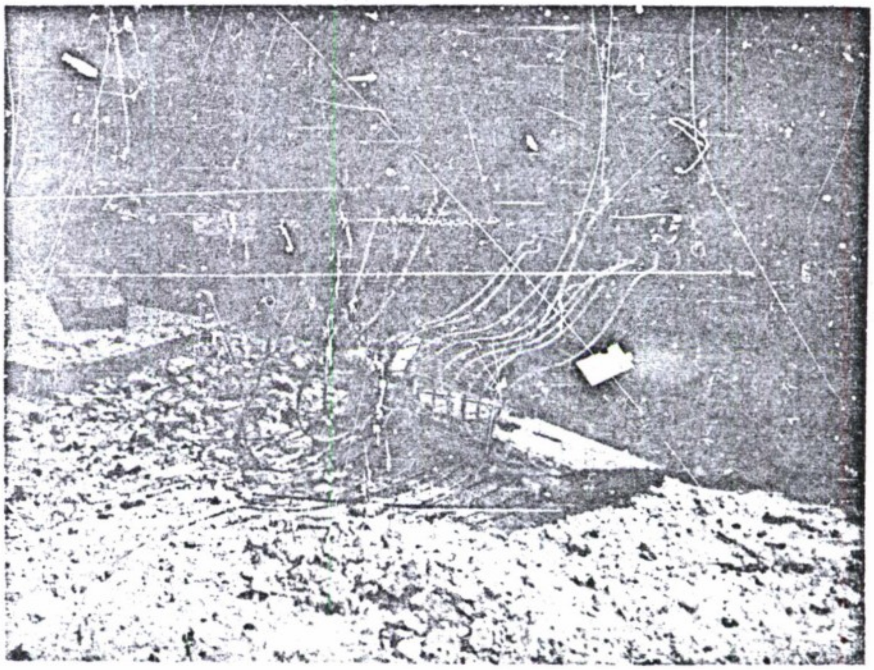


FIGURE 52
ROUND 5 -- STRENGTHENED SLAB 4
20 LBS. HE Z = 0.44
TESTED AS SIDE WALL OF CUBICLE

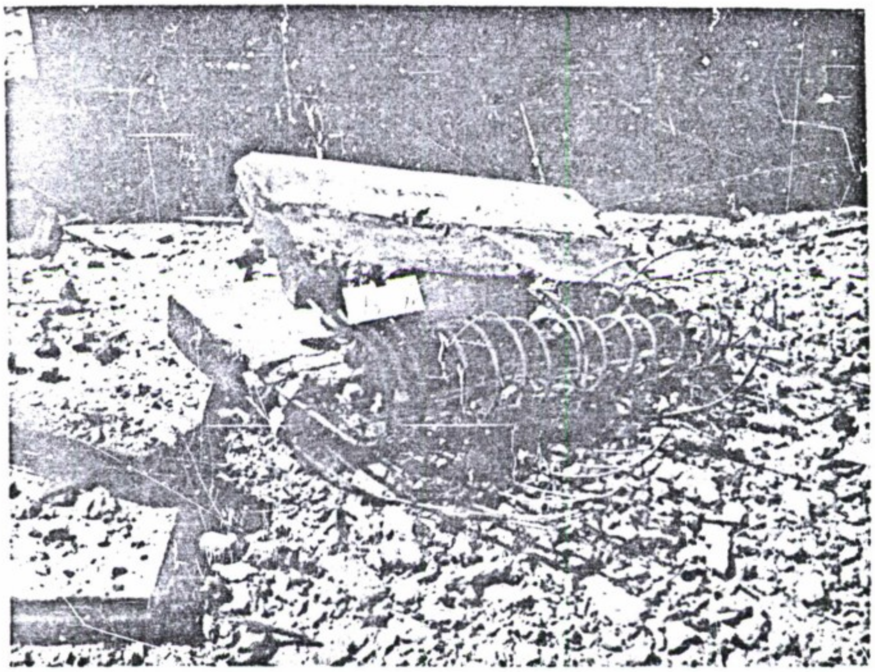


FIGURE 53
ROUND 6 -- STRENGTHENED SLAB 4
20 LBS. HE $Z = 0.8$
TESTED AS SIDE WALL OF CUBICLE

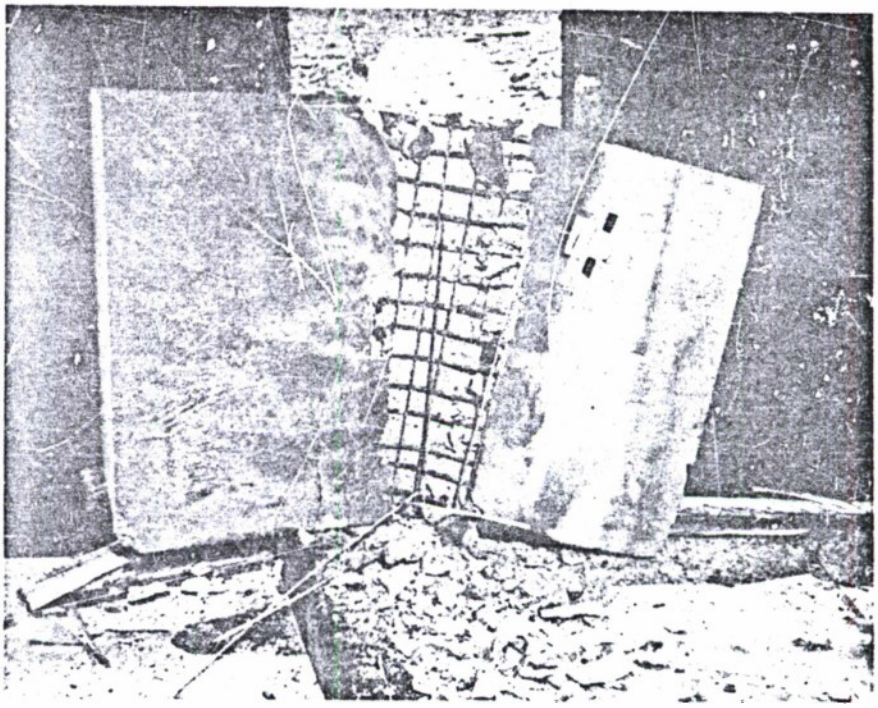


FIGURE 54
ROUND 11 -- STRENGTHENED SLAB 4
20 LBS. HE $Z = 1.25$
TESTED AS SIDE WALL OF CUBICLE

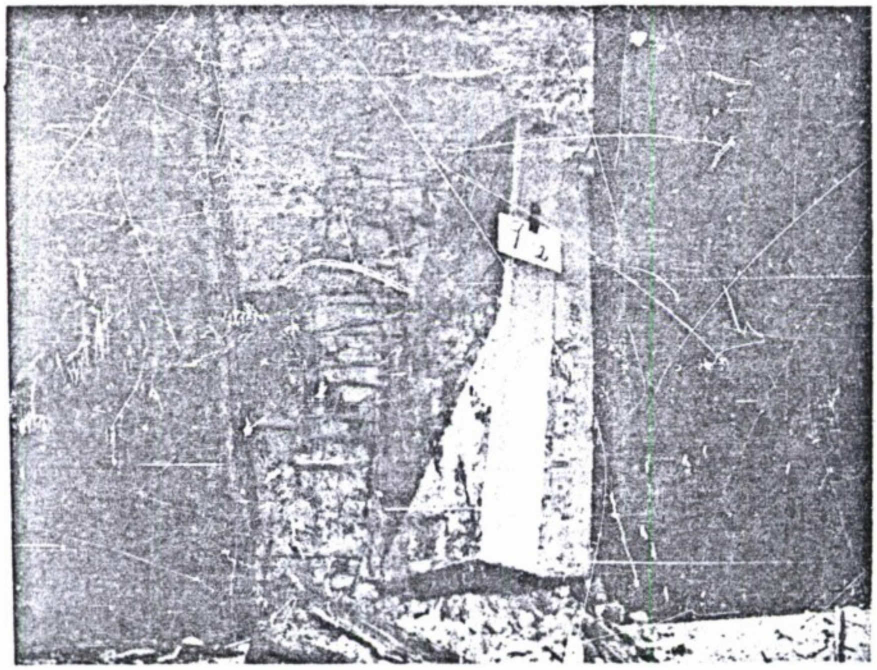


FIGURE 55
ROUND 9 -- STRENGTHENED SLAB 4
20 LBS. HE Z = 0.55
TESTED AS BACK WALL OF CUBICLE

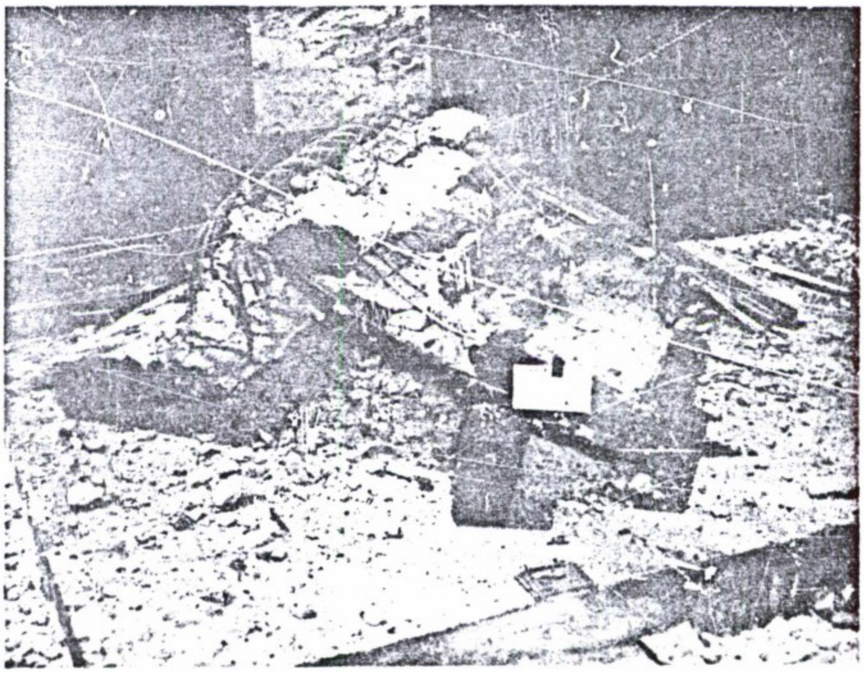


FIGURE 56
ROUND 7 -- STRENGTHENED SLAB 4
20 LBS. HE Z = 0.8
TESTED AS BACK WALL OF CUBICLE

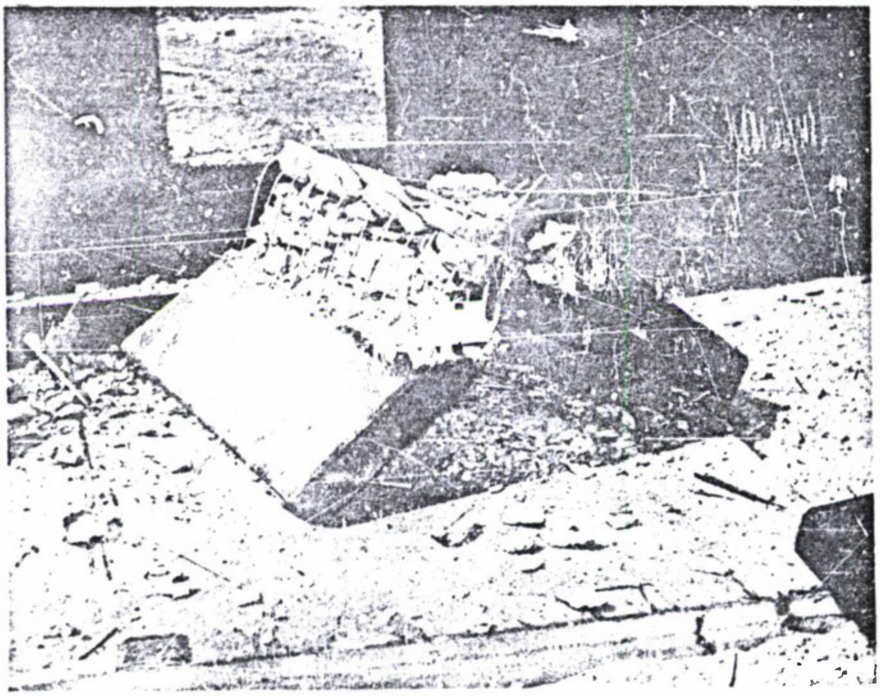


FIGURE 57
ROUND 10 -- STRENGTHENED SLAB 4
20 LBS. HE Z = 1.25
TESTED AS BACK WALL OF CUBICLE

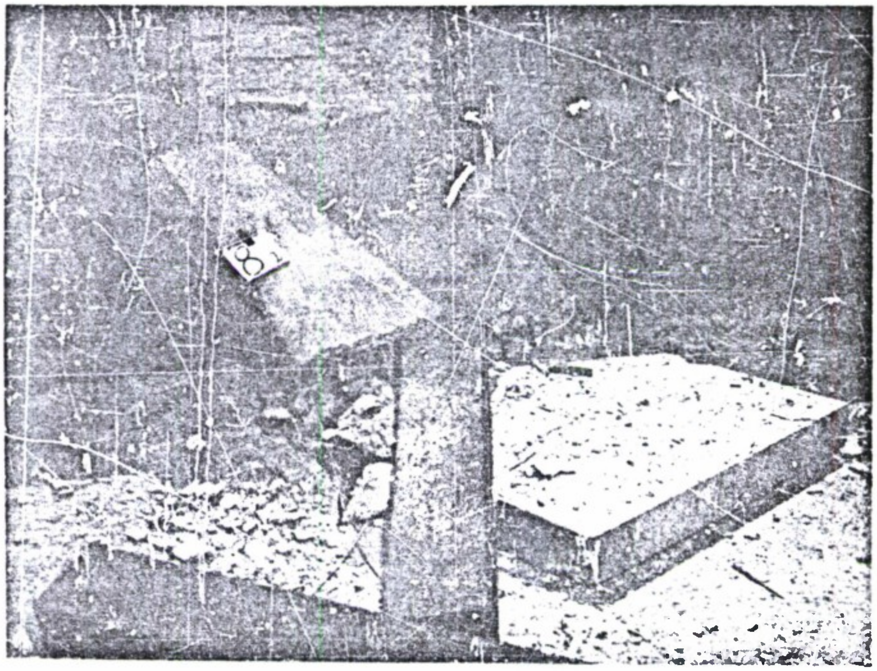


FIGURE 58
ROUND 8 -- STRENGTHENED SLAB 4
20 LBS. HE Z = 1.0
NO CUBICLE ARRANGEMENT

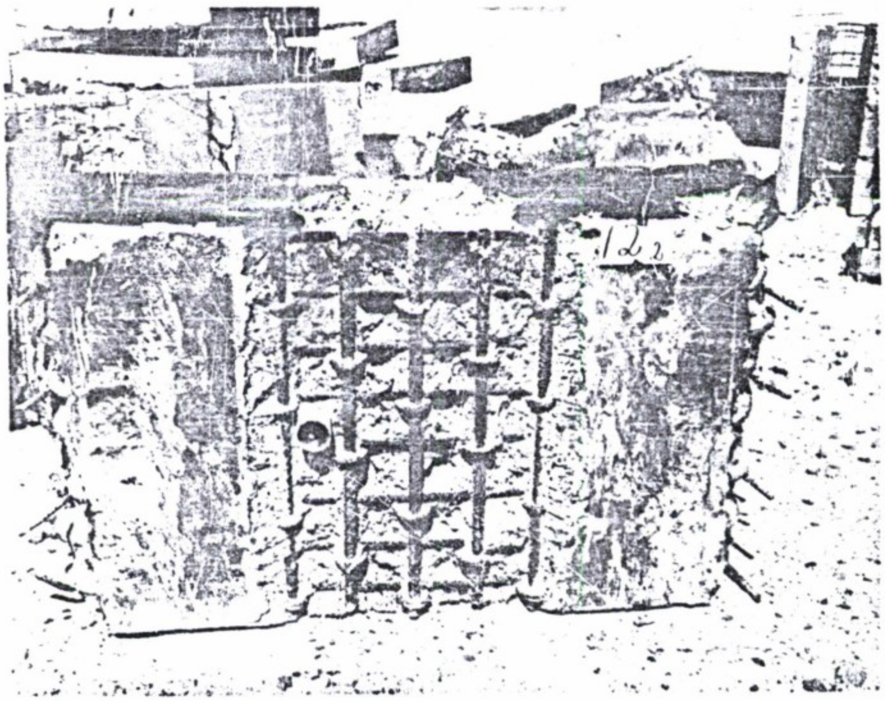
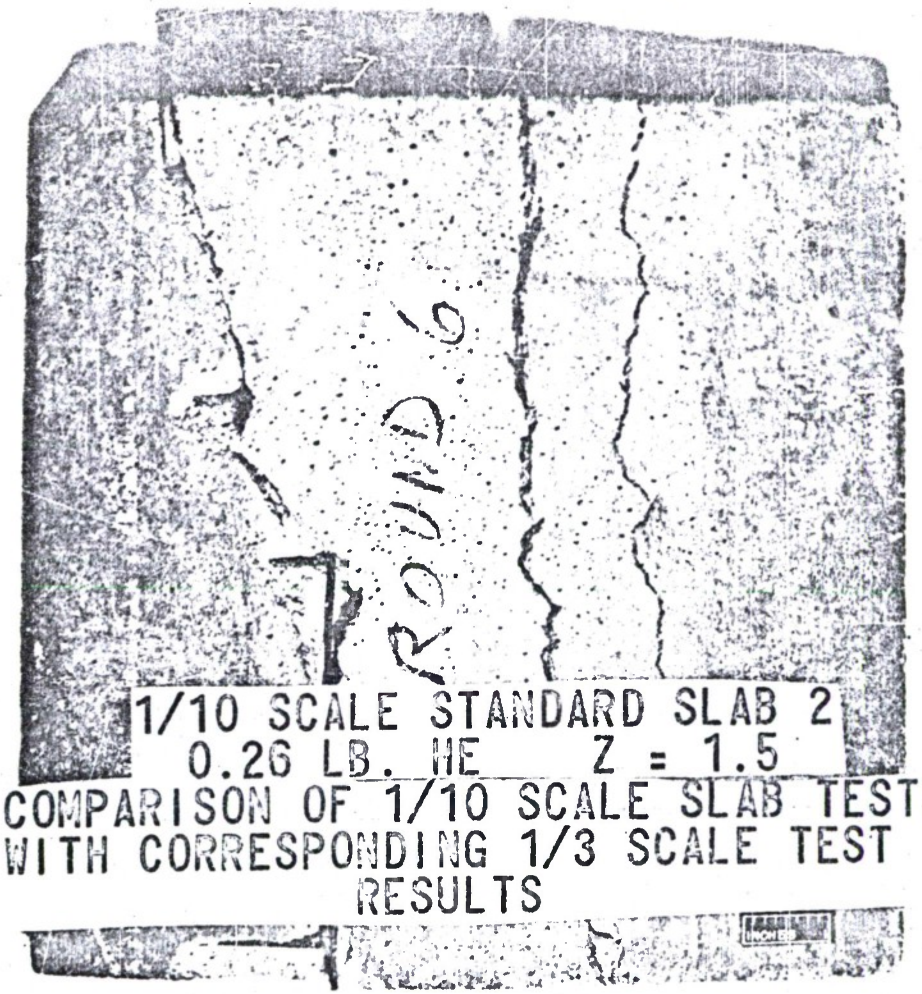


FIGURE 59
ROUND 12 -- STRENGTHENED SLAB 9
30 LBS. HE Z = 0.4
TESTED AS BACK WALL OF CUBICLE



1/10 SCALE STANDARD SLAB 2
0.26 LB. HE   Z = 1.5
COMPARISON OF 1/10 SCALE SLAB TESTS
WITH CORRESPONDING 1/3 SCALE TEST
RESULTS

ROUND 6
ACCEPTOR

FIGURE 60A

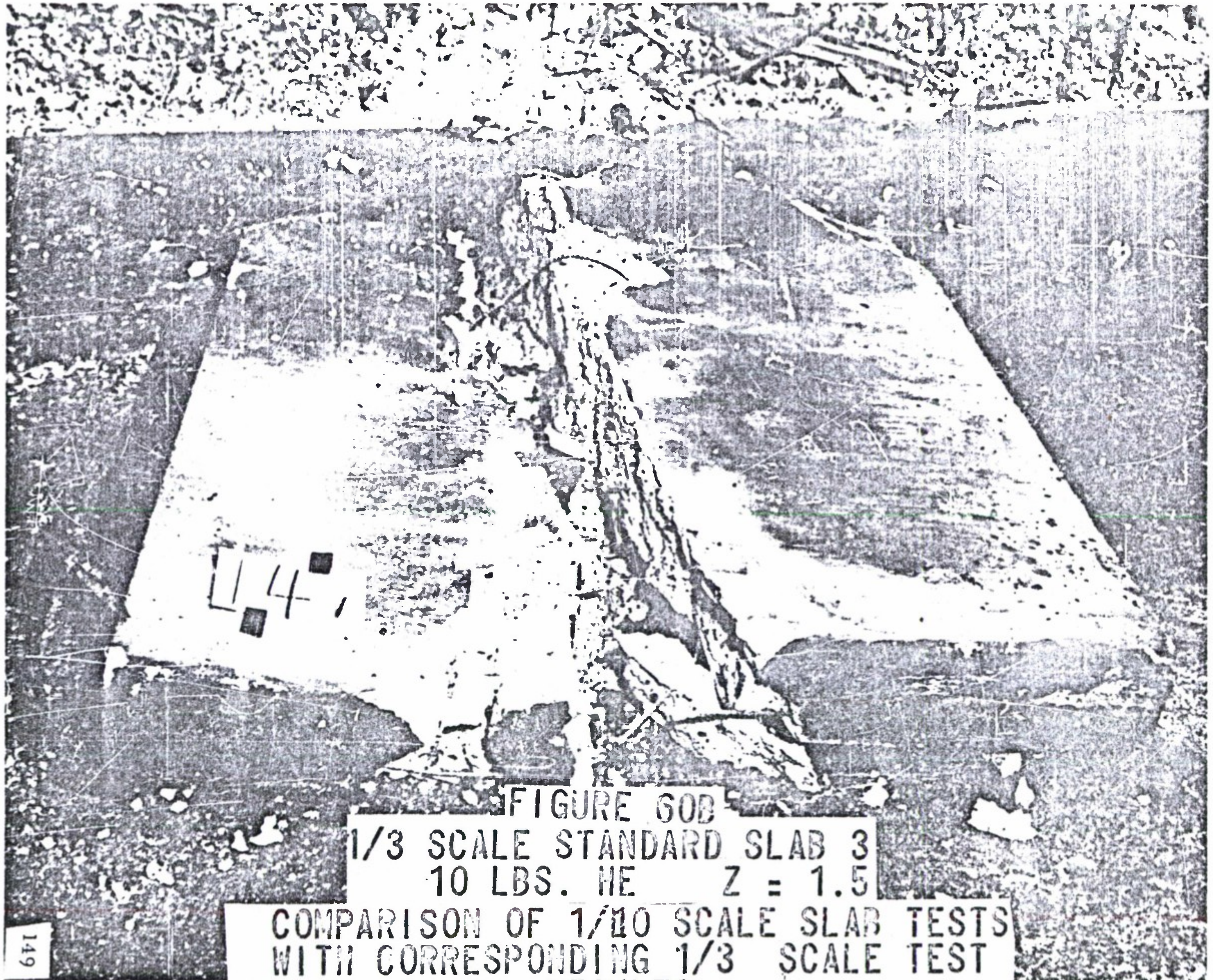


FIGURE 60B
1/3 SCALE STANDARD SLAB 3
10 LBS. HE Z = 1.5
COMPARISON OF 1/10 SCALE SLAB TESTS
WITH CORRESPONDING 1/3 SCALE TEST
RESULTS

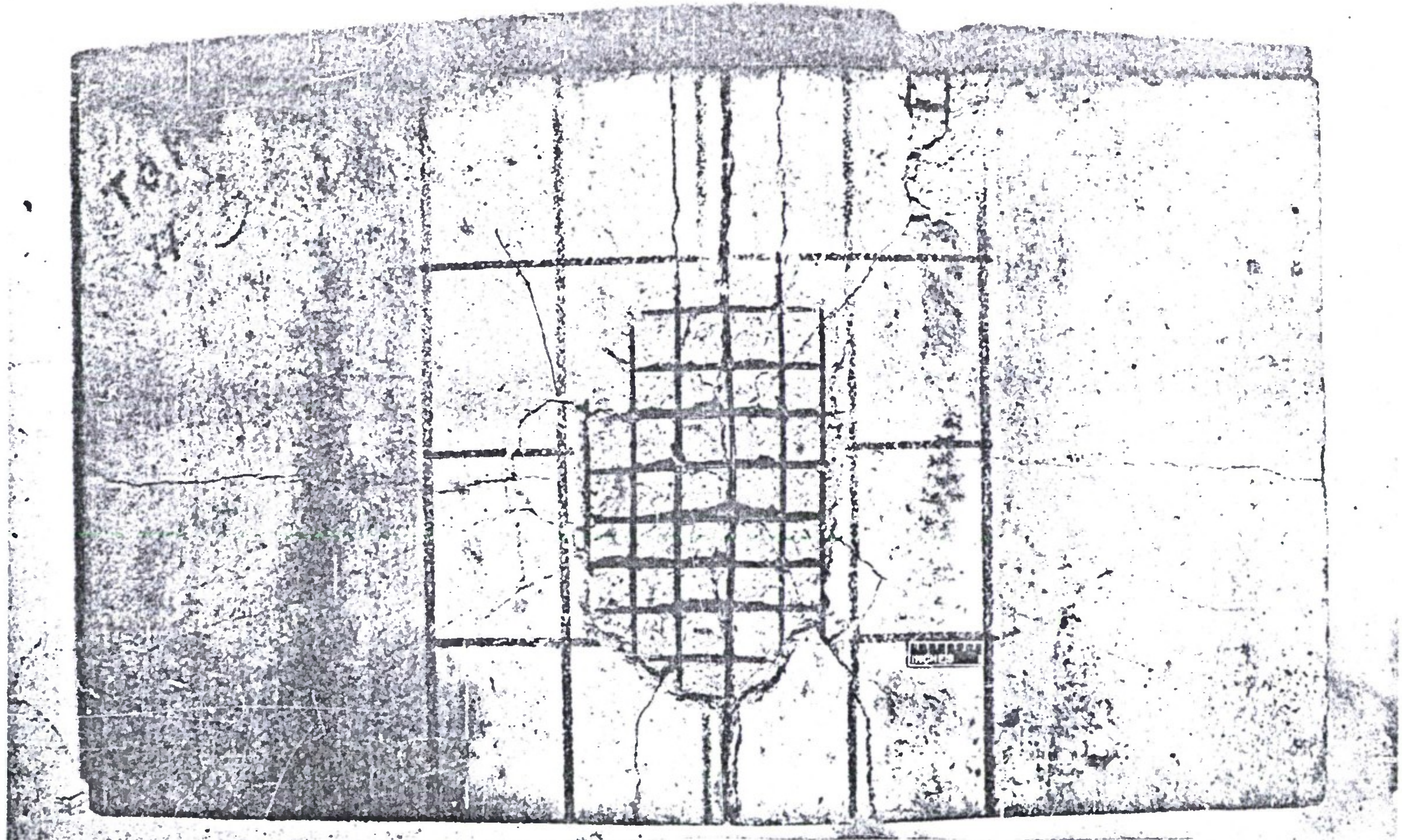


FIGURE 61A
1/10 SCALE, ROUND 7, STRENGTHENED SLAB 1
0.26 LB. HE Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TESTS
WITH CORRESPONDING 1/3 SCALE TEST
RESULTS

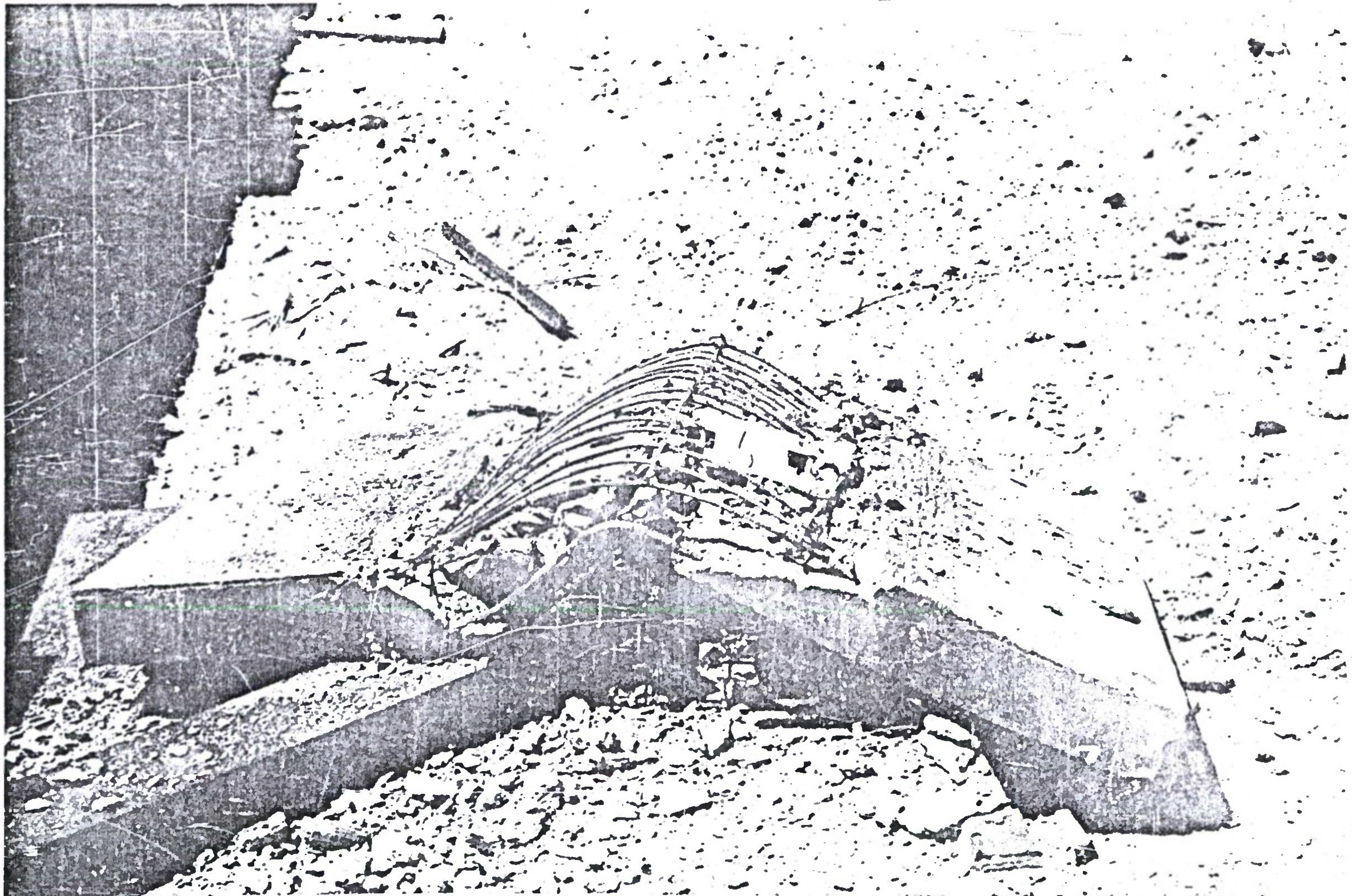


FIGURE 61B

1/3 SCALE, ROUND 5-1, STRENGTHENED SLAB 4

10 LB. HE $Z = 0.05$

COMPARISON OF 1/10 SCALE SLAB TESTS WITH CORRESPONDING 1/3 SCALE TEST RESULTS

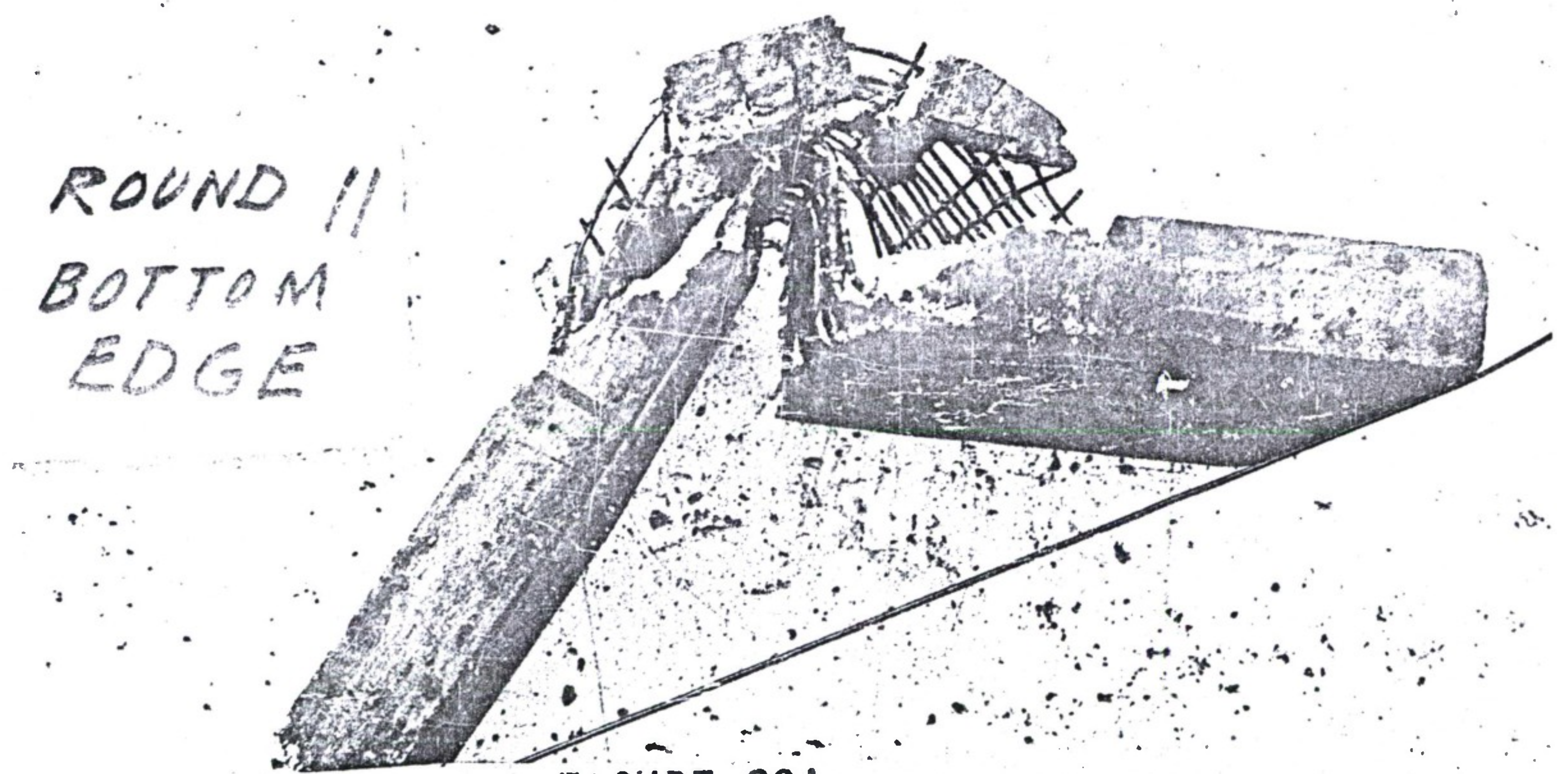
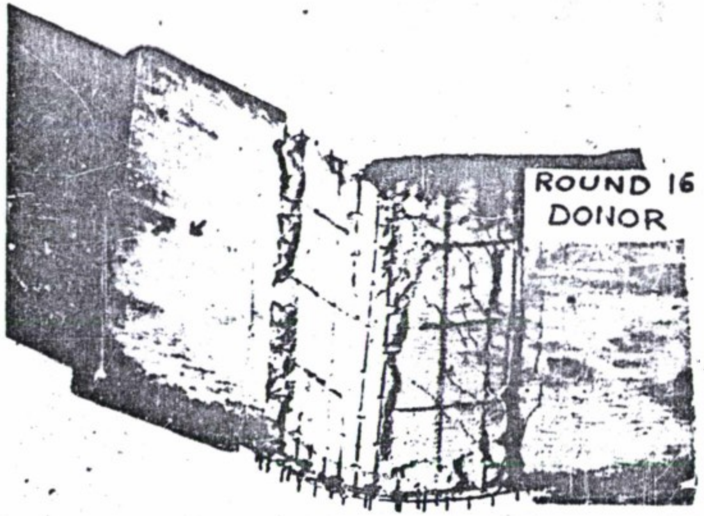
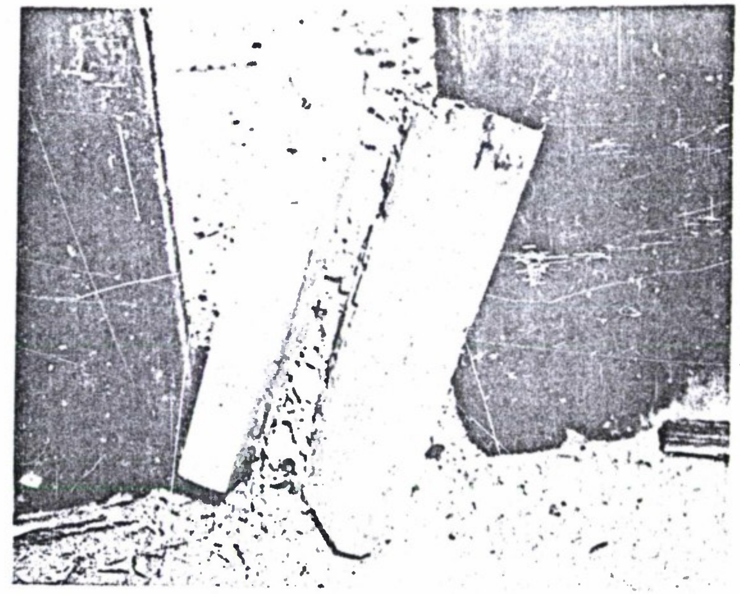


FIGURE 62A
1/10 SCALE ROUND 11, STRENGTHENED SLAB 1
0.53 LB. HE   Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TEST WITH
CORRESPONDING 1/3 SCALE TEST
RESULTS

FIGURE 62B
1/3 SCALE ROUND 6-1, STRENGTHENED SLAB 4
10 LBS. HE Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TEST WITH
CORRESPONDING 1/3 SCALE TEST RESULTS



1/10 SCALE SLAB ROUND 16
Z = 0.5 W = 0.53 LB.



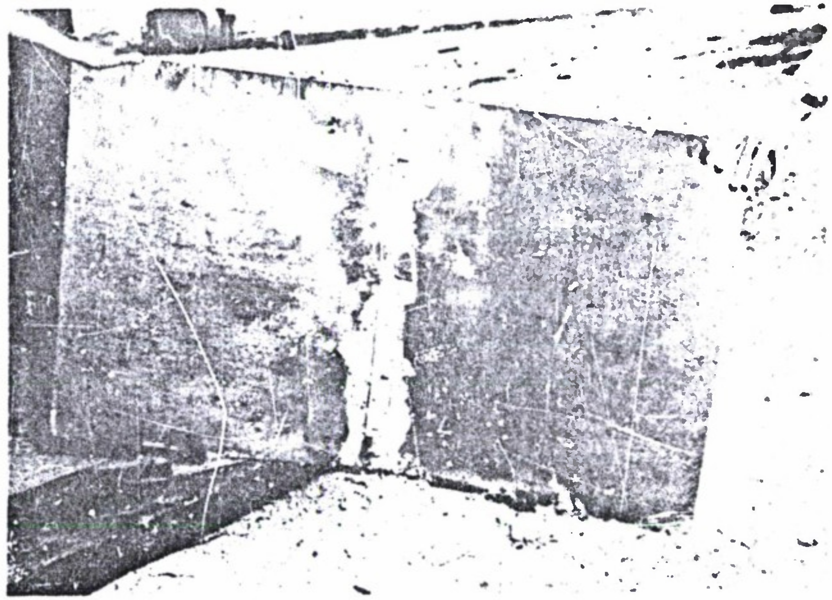
1/3 SCALE SLAB ROUND 9-1
Z = 0.5 W = 20 LBS

FIGURE 63
COMPARISON OF 1/10 SCALE TEST SLAB WITH
A CORRESPONDING 1/3 SCALE TEST SLAB RESULTS

COMPARISON OF 1/10 SCALE WITH A CORRESPONDING 1/3 SCALE TEST SLAB RESULTS

1/10 SCALE SLAB ROUND 19

Z = 0.8 W = 0.53 LB



1/3 SCALE SLAB ROUND 8-1

Z = 1.25 W = 20 LBS.

FIGURE 64

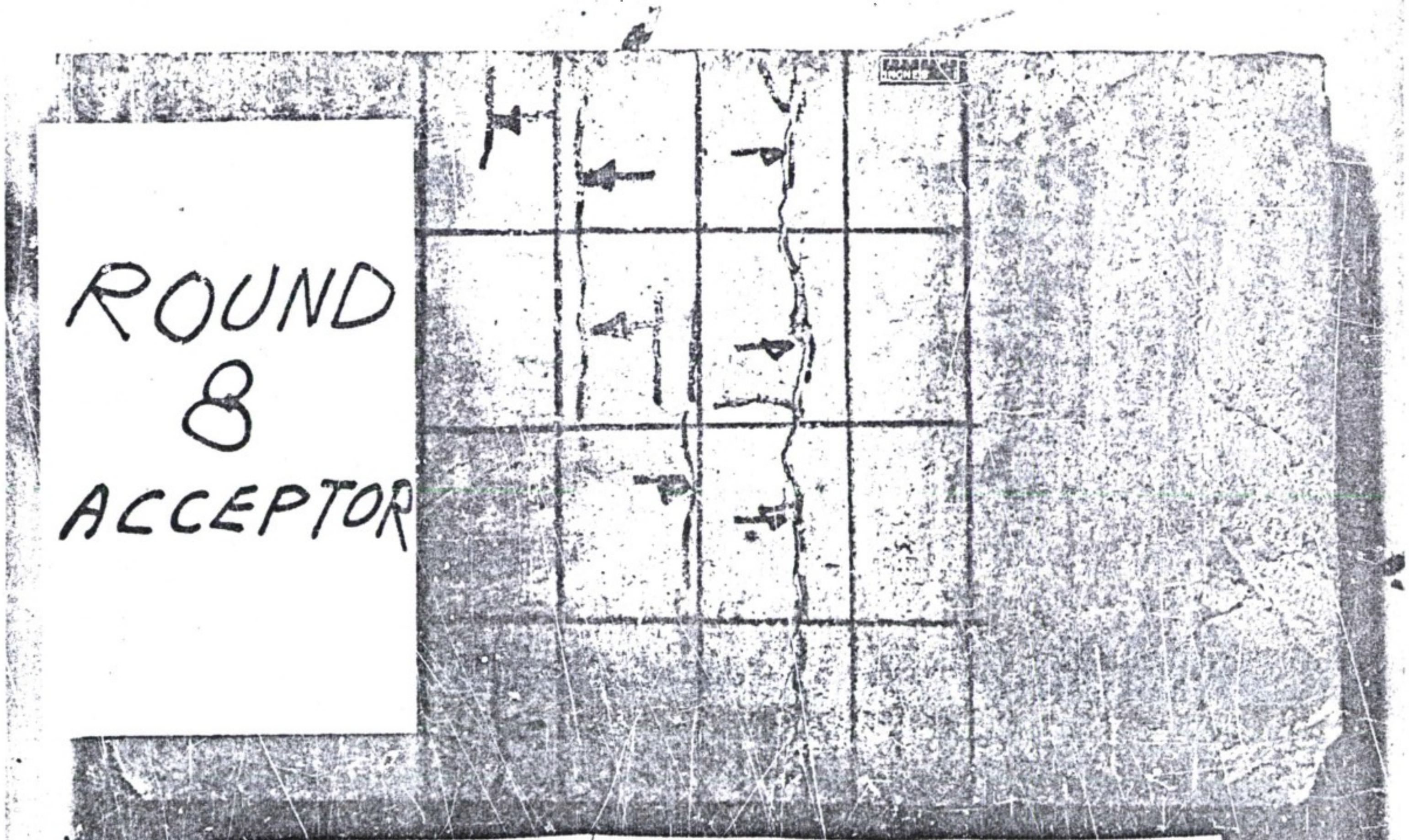


FIGURE 65A
1/10 SCALE, ROUND 8, STRENGTHENED SLAB 3
0.83 LB. HE Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TESTS WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

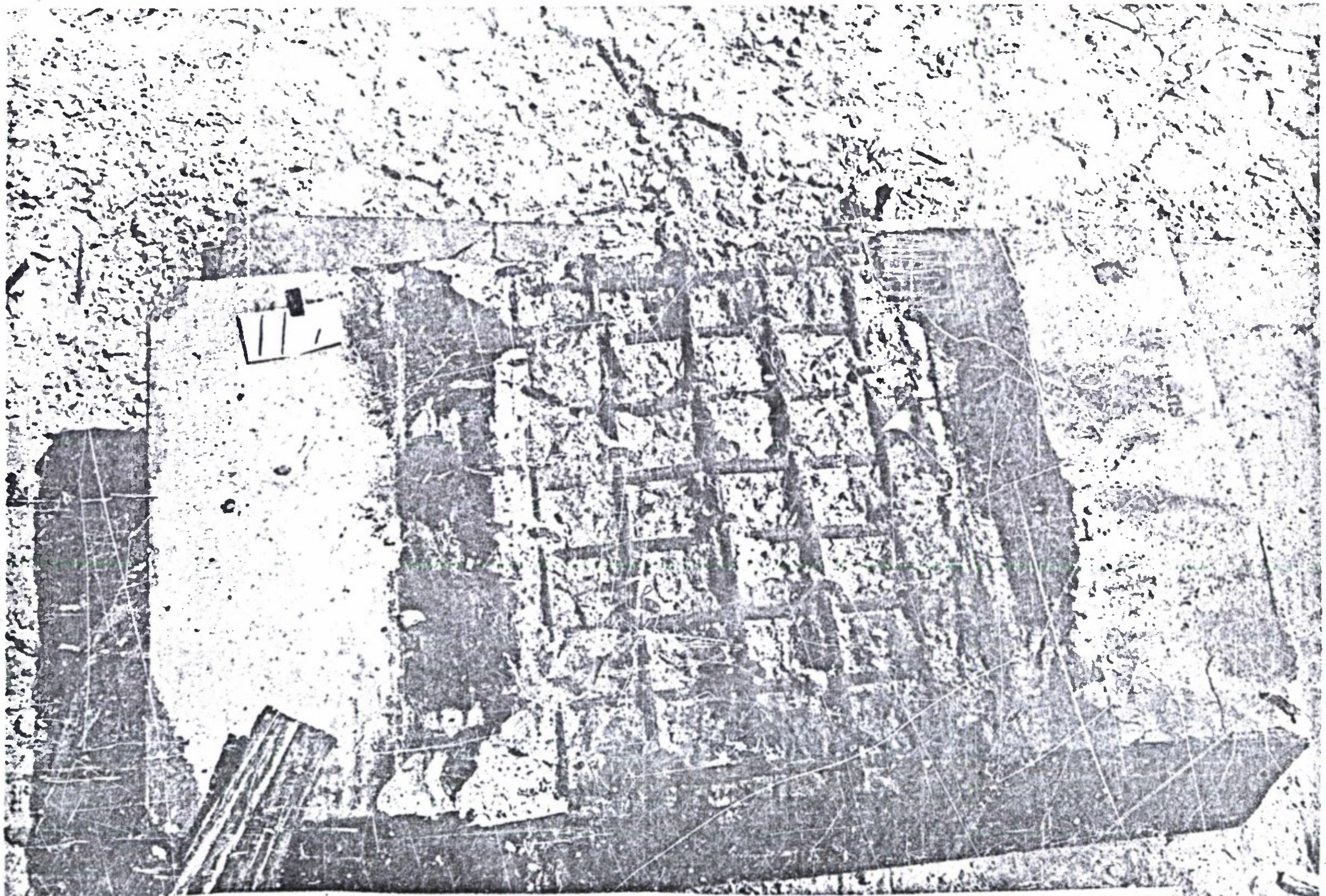


FIGURE 65B
1/3 SCALE, ROUND 11-1, STRENGTHENED SLAB 8
30 LBS. HE Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TESTS WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

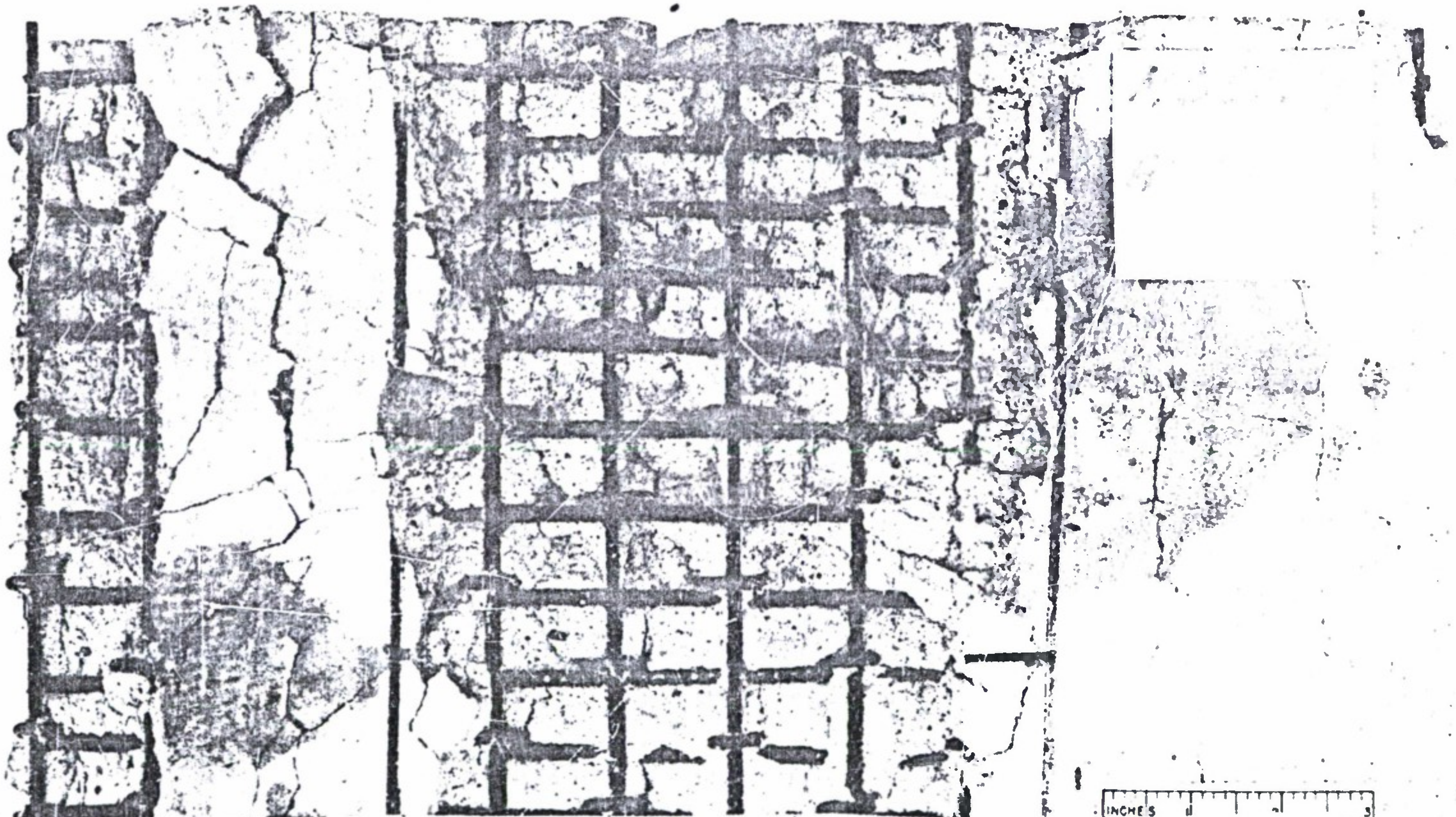


FIGURE 66A
1/10 SCALE, ROUND 12, STRENGTHENED SLAB 3
0.81 LB. HE Z = 0.4
TESTED AS BACK WALL OF CUBICLE
COMPARISON OF 1/LO SCALE SLAB TESTS WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

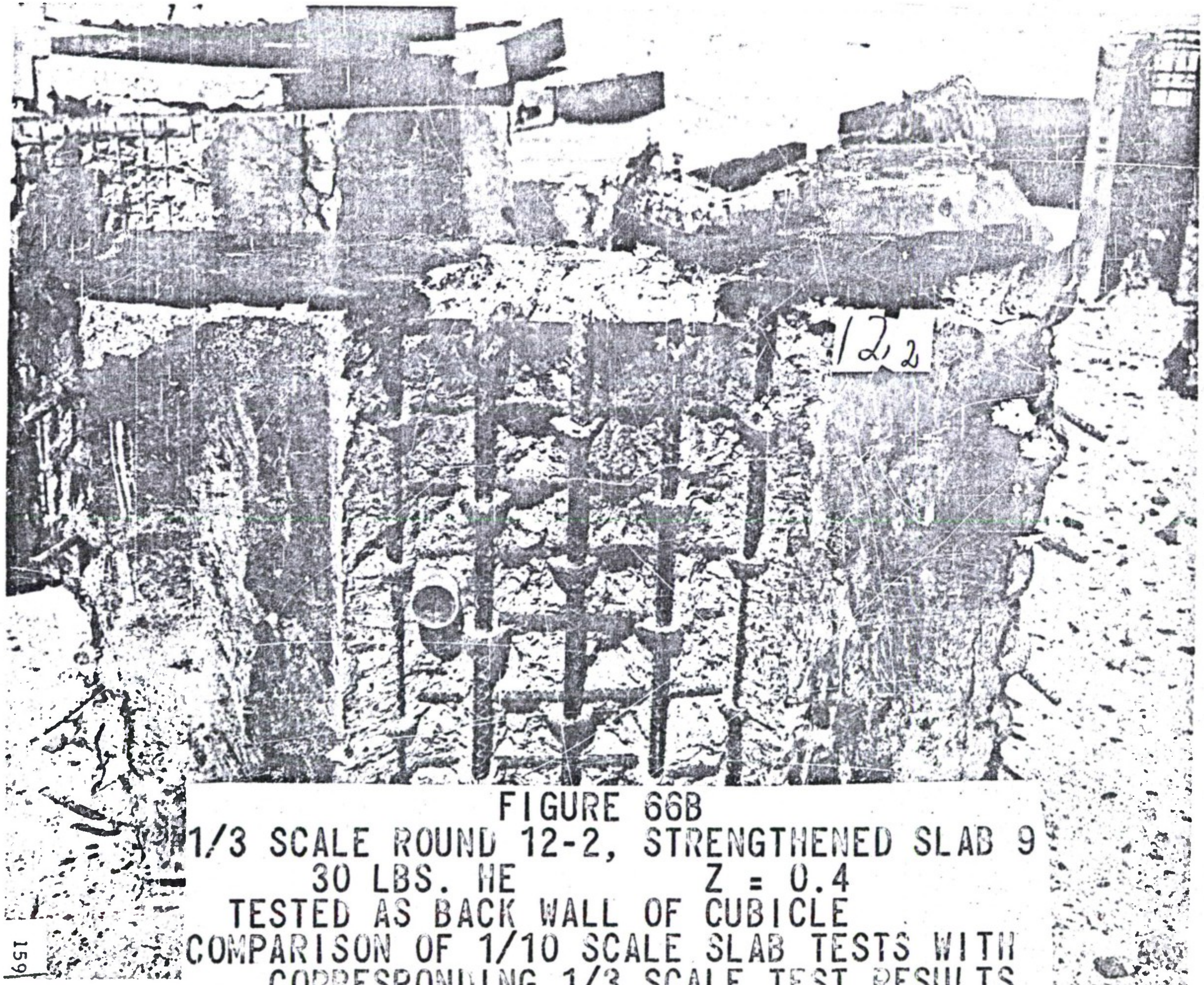


FIGURE 66B
1/3 SCALE ROUND 12-2, STRENGTHENED SLAB 9
30 LBS. HE Z = 0.4
TESTED AS BACK WALL OF CUBICLE
COMPARISON OF 1/10 SCALE SLAB TESTS WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

FIGURE 67A
1/10 SCALE ROUND 17, STRENGTHENED SLAB 4
0.81 LB. HE Z = 0.5
TESTED AS SIDE WALL OF CUBICLE
COMPARISON OF 1/10 SCALE SLAB TESTS WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

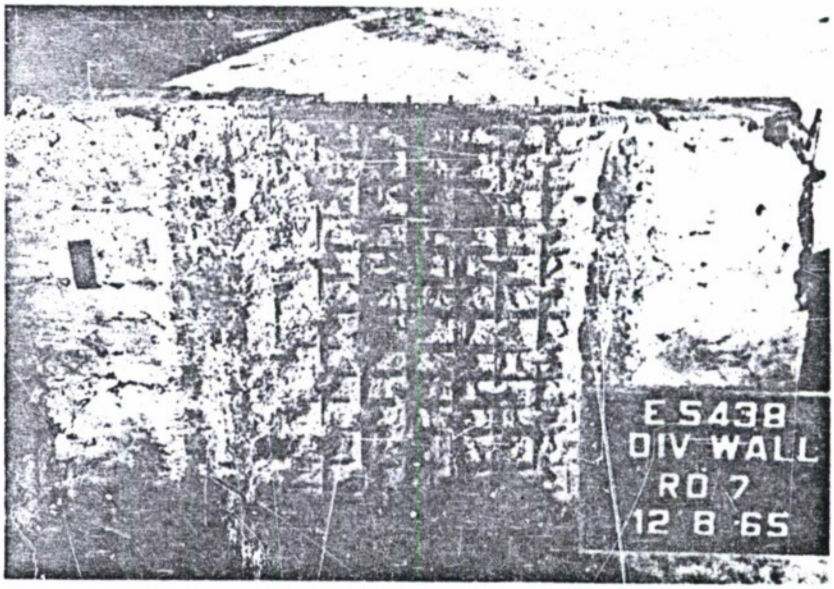


FIGURE 67B
1/3 SCALE, ROUND 7, STRENGTHENED SLAB 14
30 LBS. HE Z = 0.5
TESTED AS BACK WALL OF CUBICLE
COMPARISON OF 1/10 SCALE SLAB TESTS WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

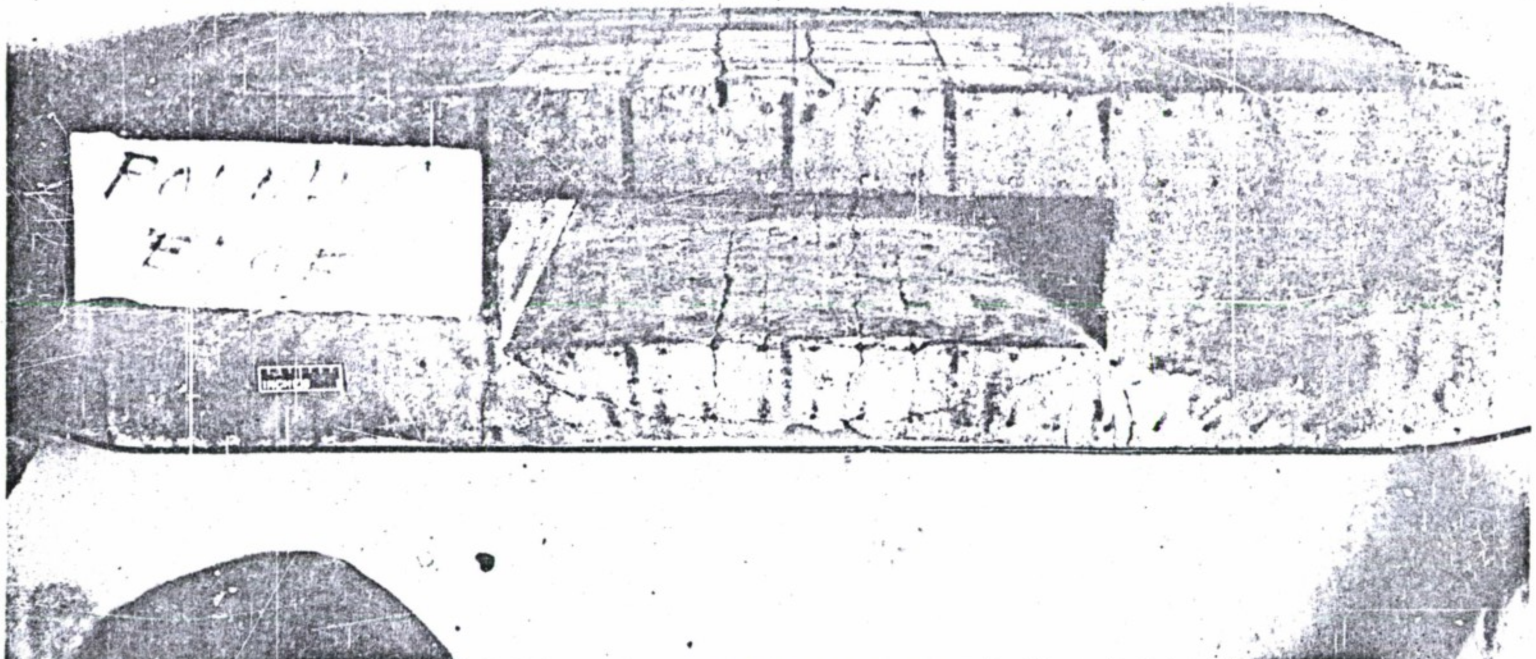


FIGURE 68A
1/10 SCALE, ROUND 9, COMPOSITE SLAB 1
0.53 LB. HE Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TESTS WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

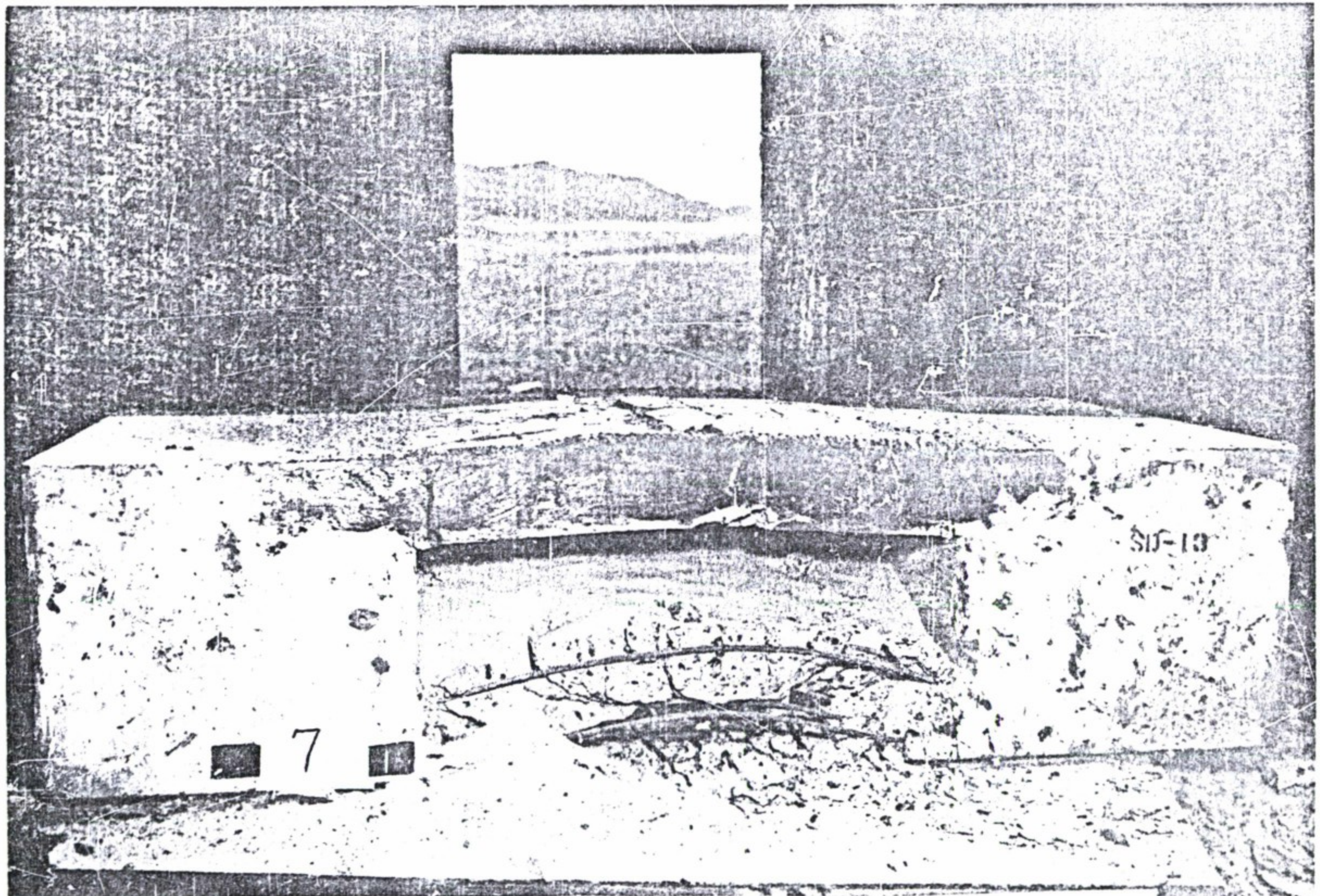


FIGURE 68B
1/3 SCALE, ROUND 7-1, COMPOSITE SLAB 2
20 LBS. HE Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TESTS WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

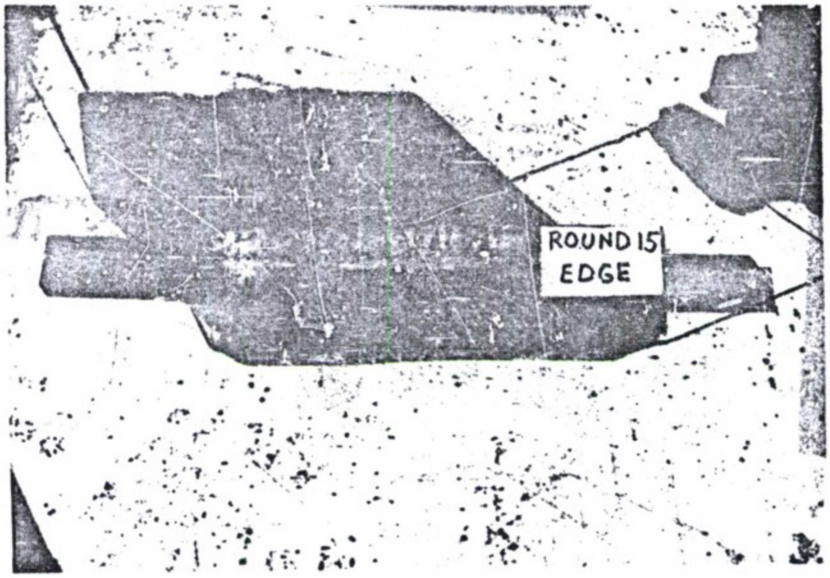


FIGURE 69A
1/10 SCALE, ROUND 15, COMPOSITE SLAB 2
0.81 LB. HE   Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TESTS WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

FIGURE 69B
1/3 SCALE, ROUND 16-1, COMPOSITE SLAB 5
30 LBS.HE Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TESTS WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

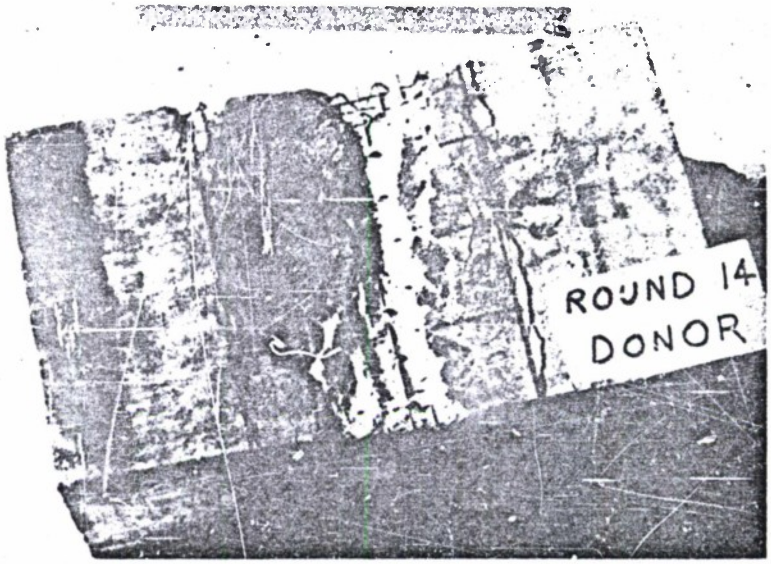


FIGURE 70A
1/10 SCALE, ROUND 14, COMPOSITE SLAB 3
0.80 LB. HE Z = 0.40
COMPARISON OF 1/10 SCALE SLAB TEST WITH CORRESPONDING 1/3 SCALE TEST RESULTS

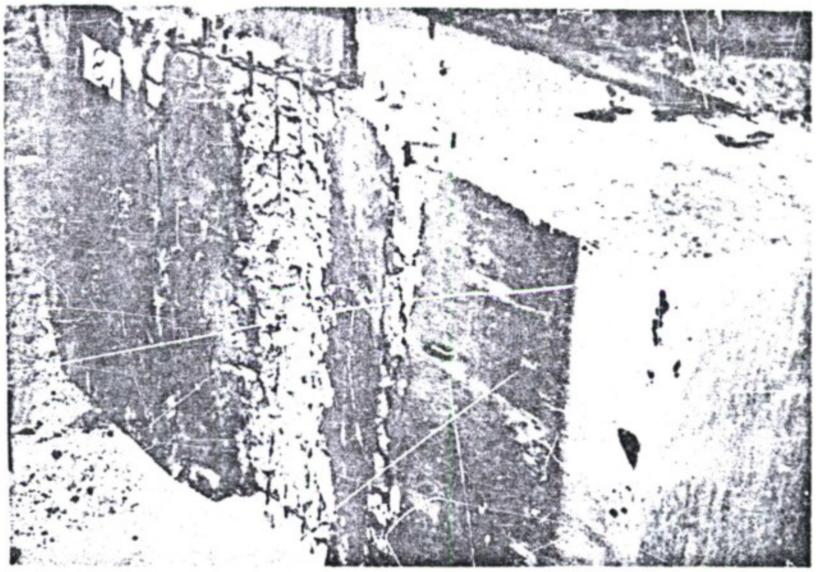


FIGURE 70B
1/3 SCALE, ROUND 18-1, COMPOSITE SLAB 6
30 LBS. HE   Z = 0.40
TESTED AS BACK WALL OF CUBICLE
COMPARISON OF 1/10 SCALE SLAB TEST WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

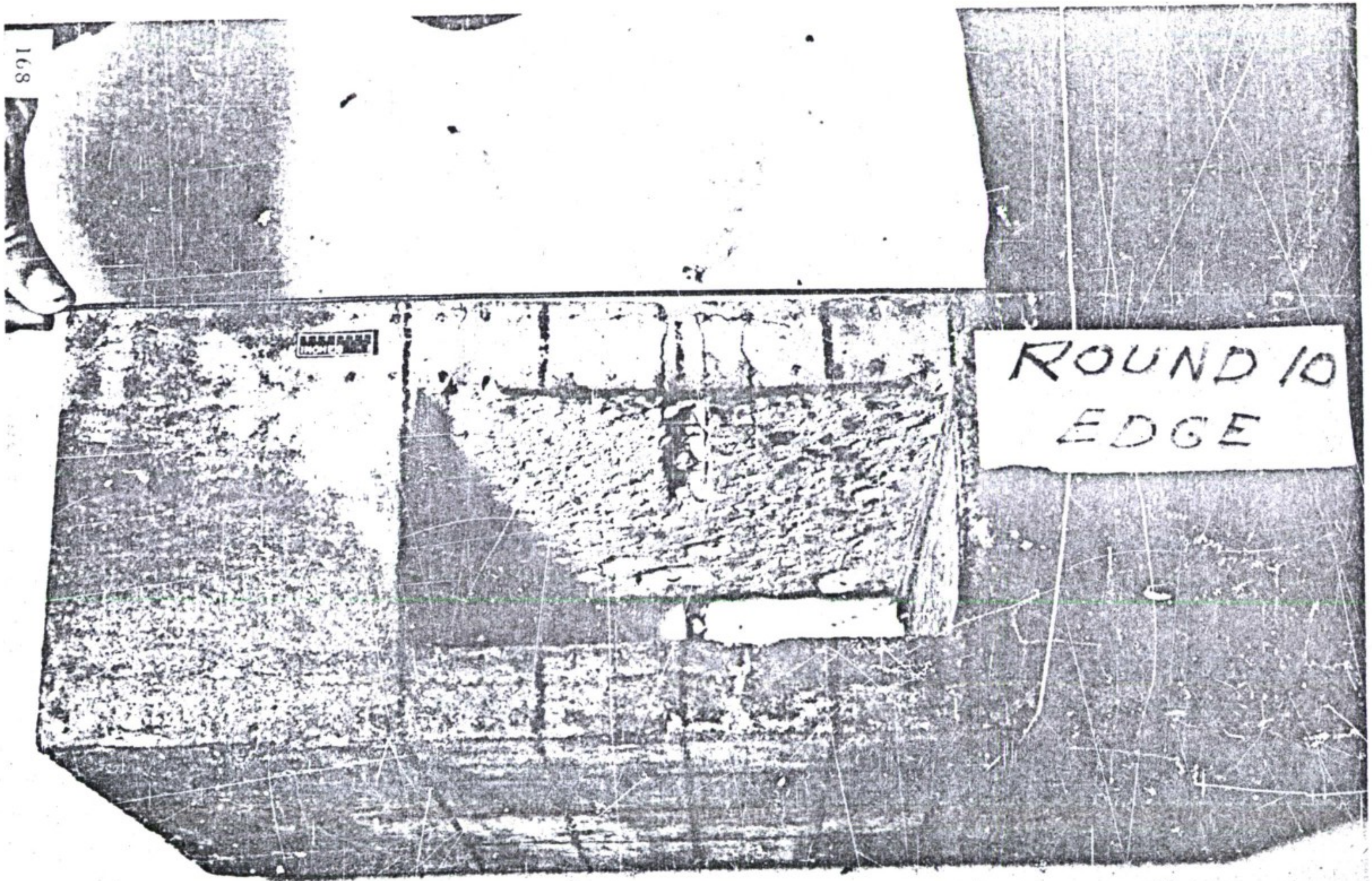


FIGURE 71A
1/10 SCALE, ROUND 10, COMPOSITE SLAB 3
1.08 LBS. HE Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TEST WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

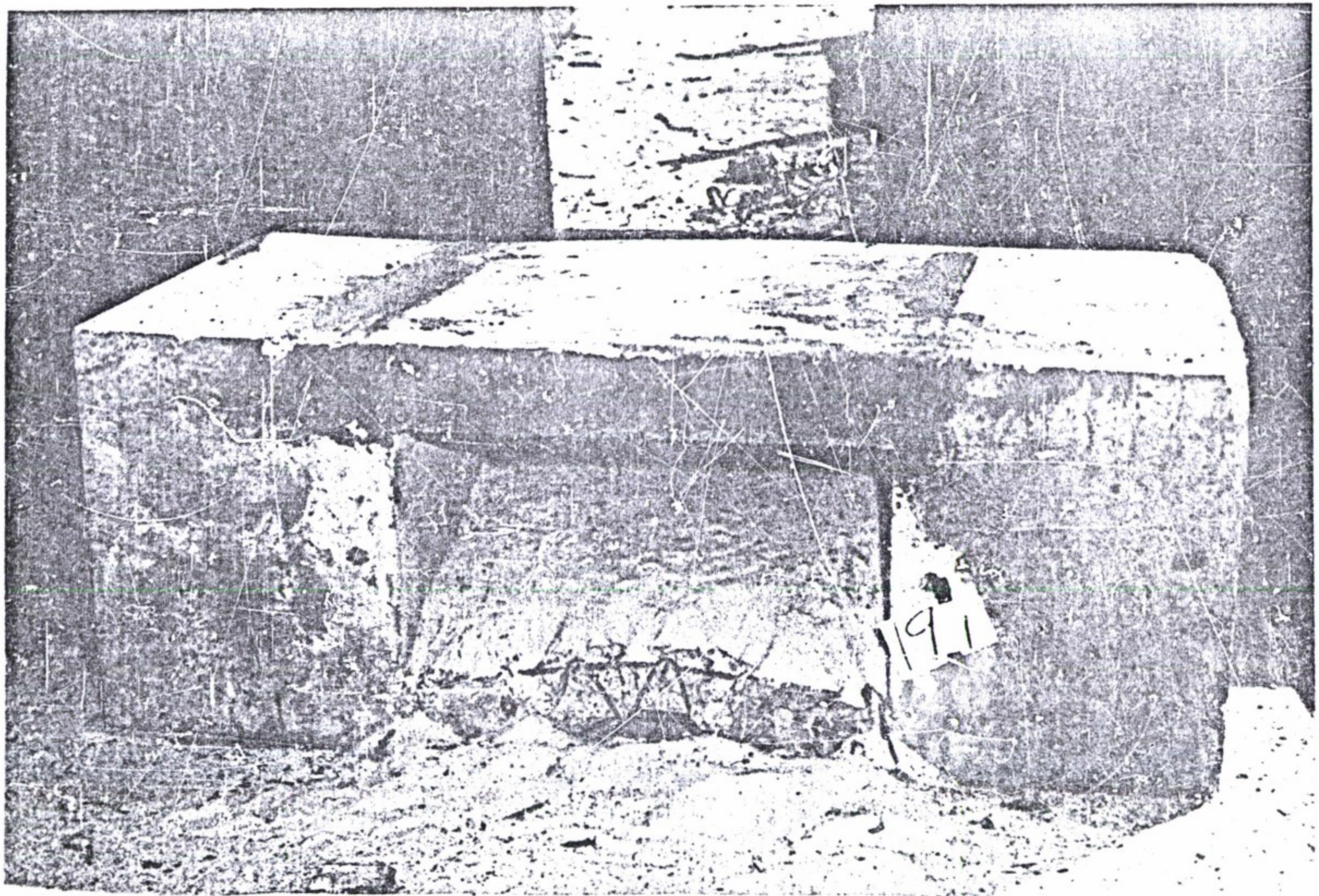


FIGURE 71B
1/3 SCALE, ROUND 19-1, COMPOSITE SLAB 6
40 LBS. HE Z = 0.5
COMPARISON OF 1/10 SCALE SLAB TEST WITH
CORRESPONDING 1/3 SCALE TEST RESULTS

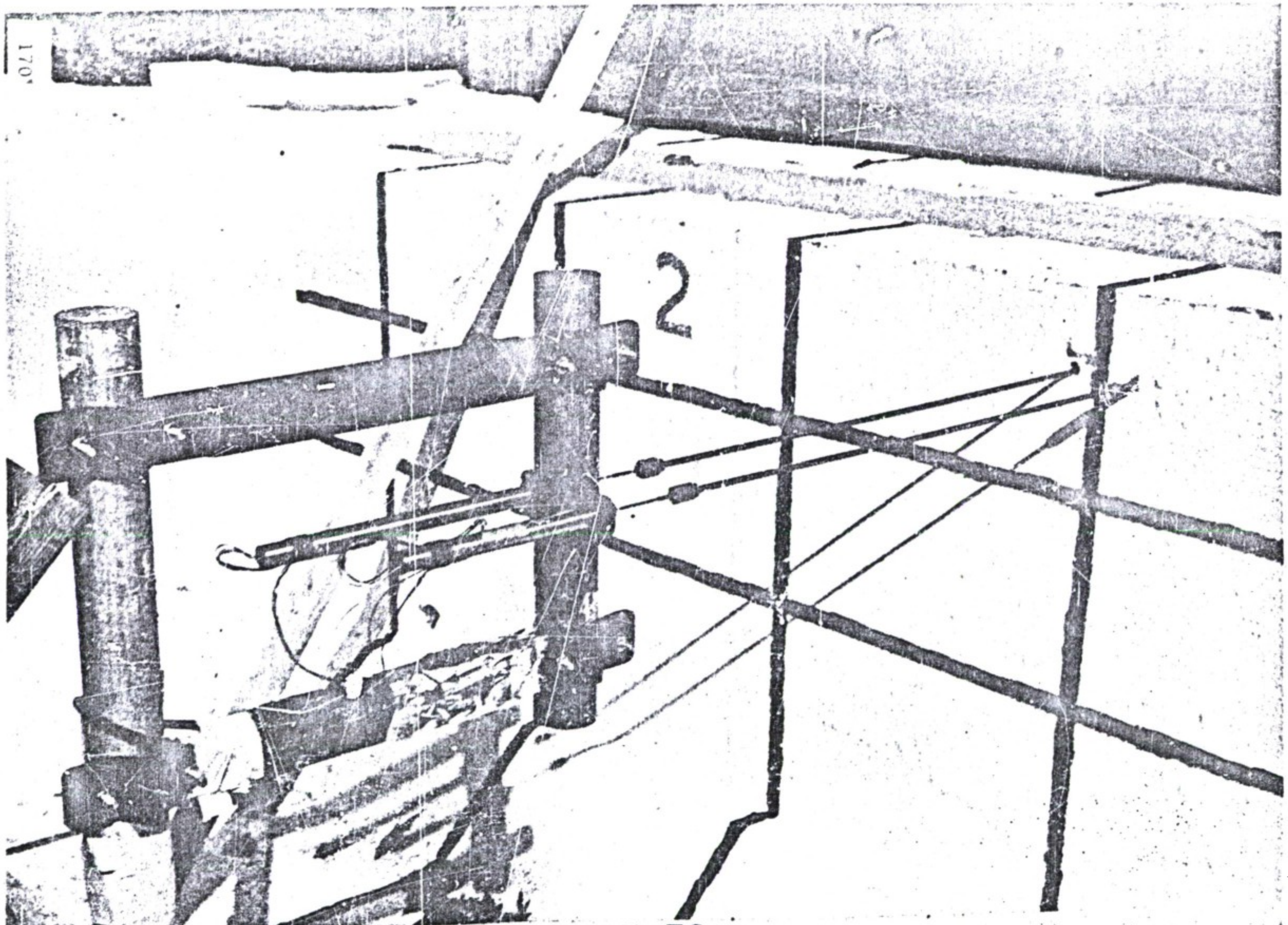


FIGURE 72
WALL REFLECTION GAGES MOUNTED TO INNER AND OUTER BACK WALL OF 1/3 SCALE BAY STRUCTURE

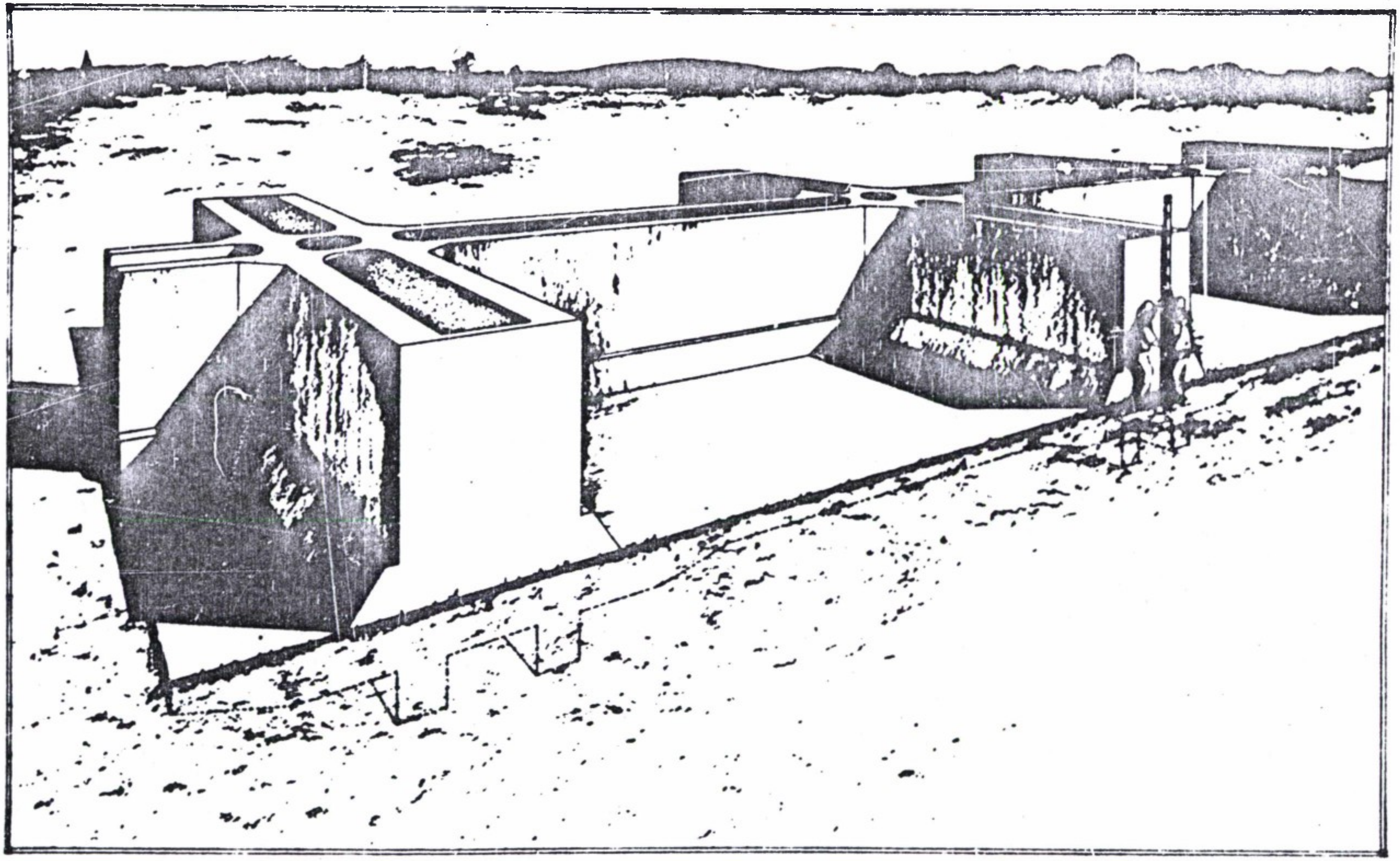


FIGURE 73
PROTOTYPE OF BAY STRUCTURE

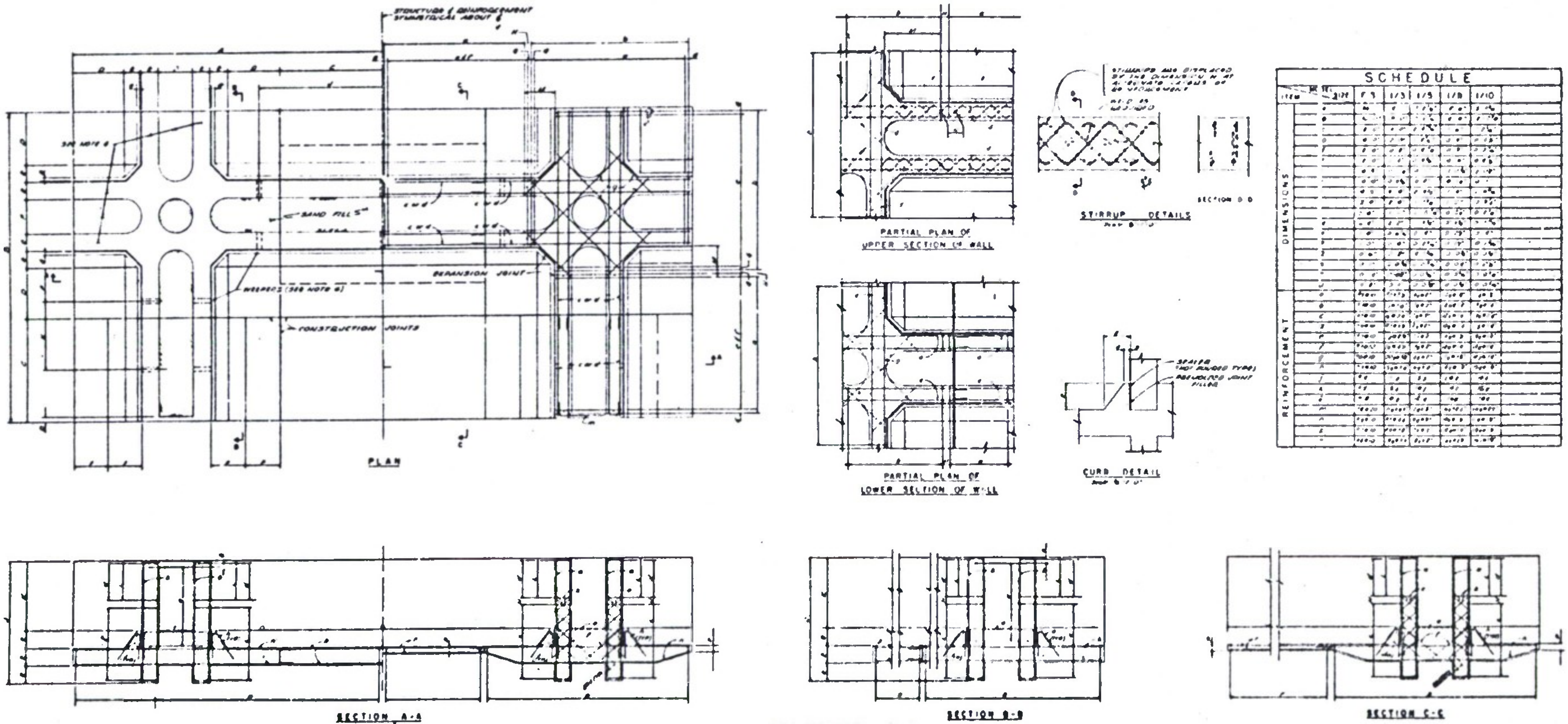


FIGURE 74
MODEL LAYOUT, EXPLOSIVE STORAGE BAY
(2,000 LB. CAPACITY) MODEL SCALE,
BAY TEST SERIES

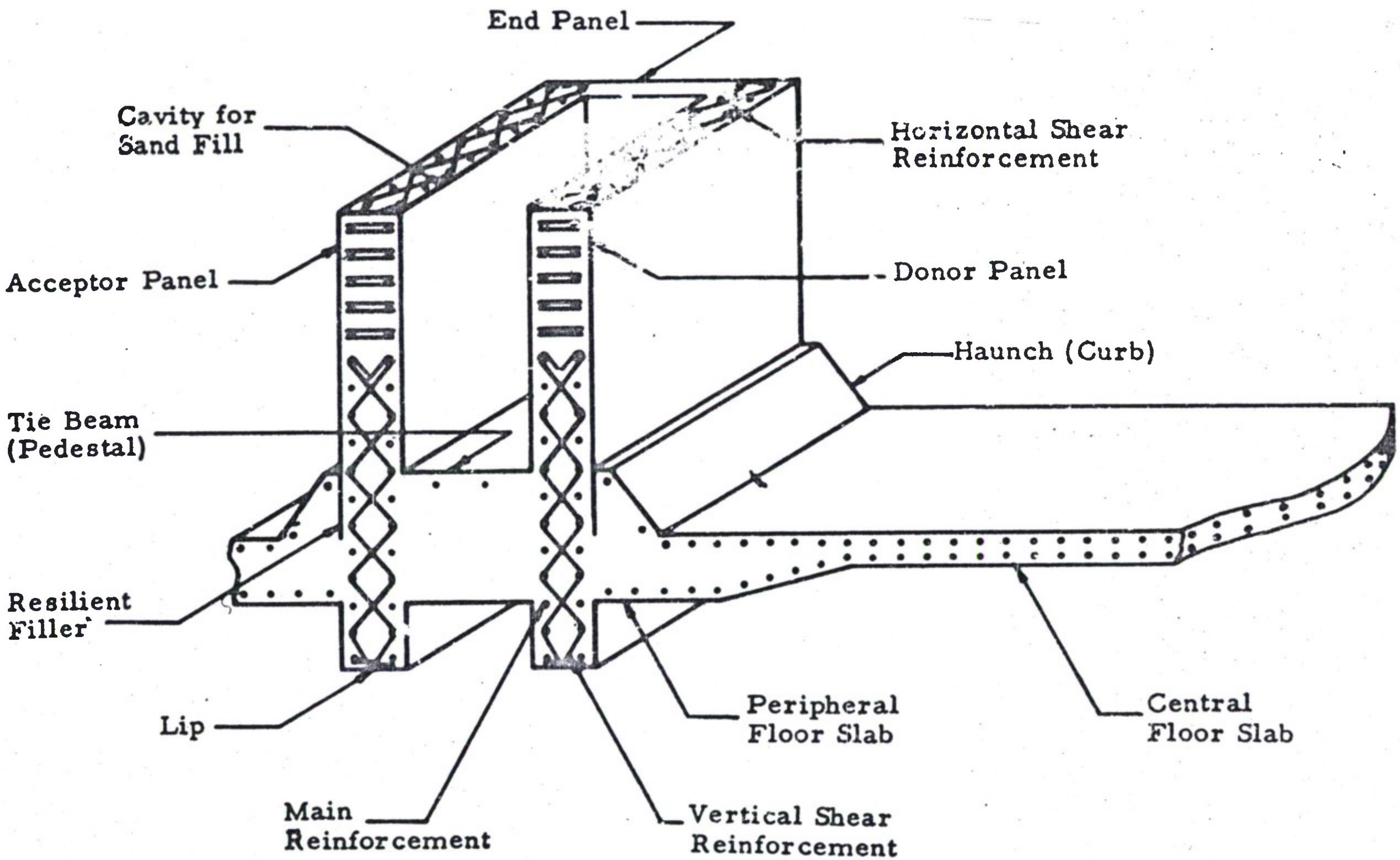
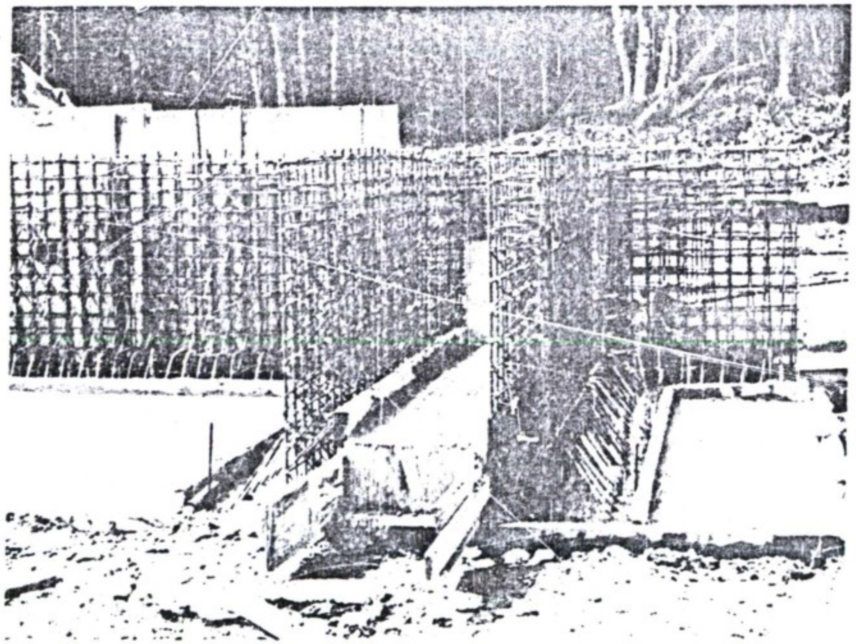
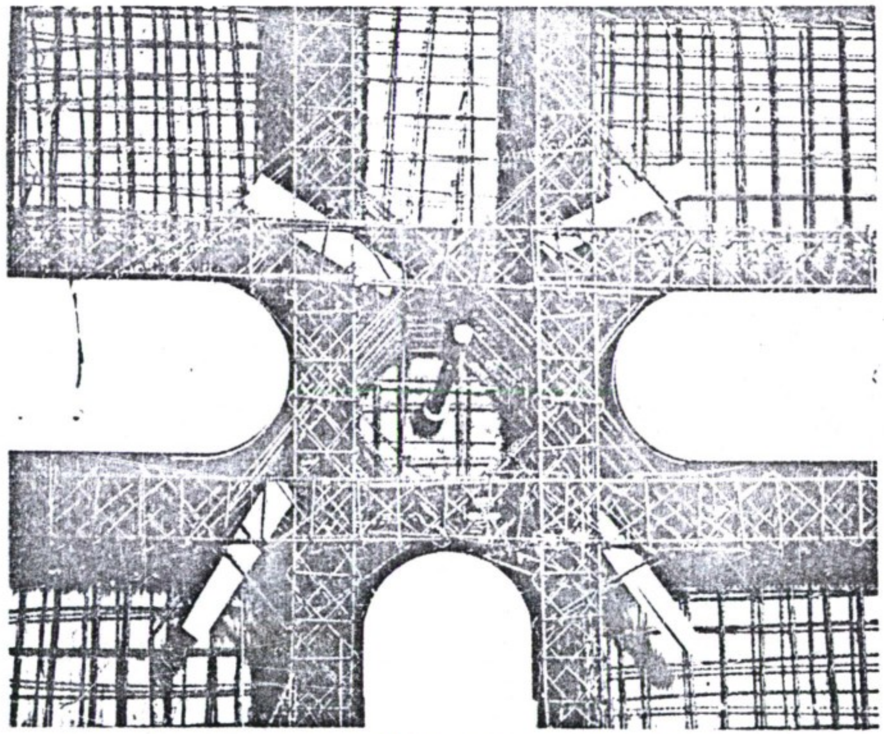


FIGURE 75
TYPICAL WALL AND FLOW SECTION SHOWING

REINFORCING PATTERNS FOR TEST BAY



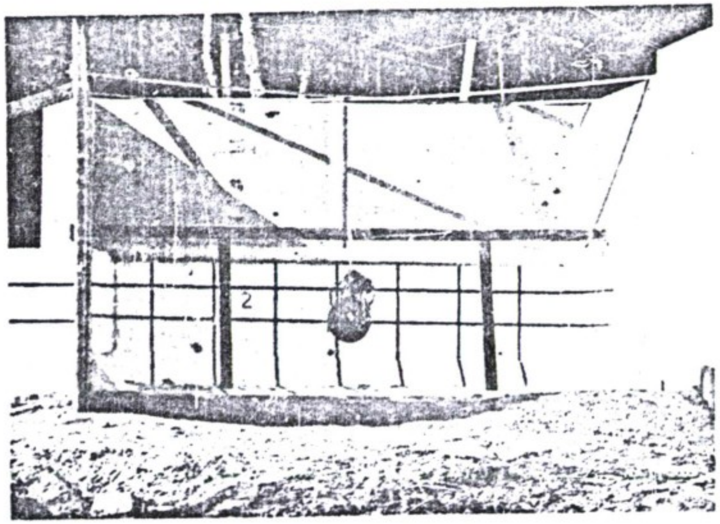
1/3 SCALE MODEL REINFORCING AFTER POURING OF MONOLITHIC FLOOR SLAB AND PEDESTAL. SHOWS ATTACHMENT OF WALL TO FLOOR SLAB AND PEDESTAL.



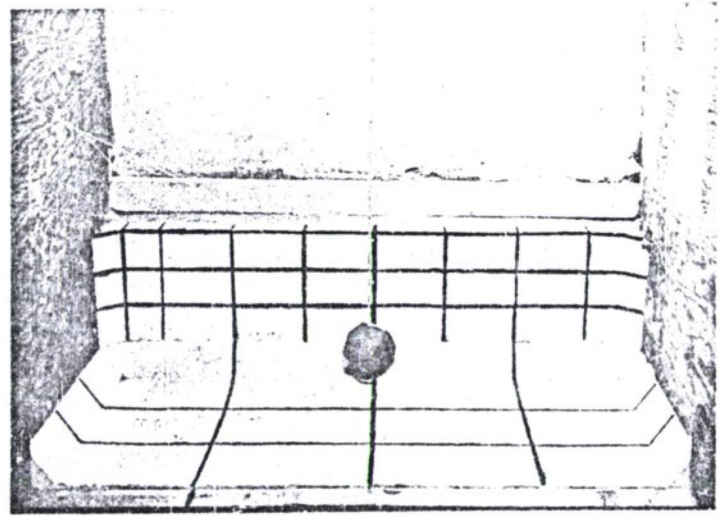
DETAIL OF 1/10 SCALE BAY REINFORCING SHOWING CORNER FILLETS AND STIRRUPS FOR FULL DEVELOPMENT OF TENSION REINFORCEMENT

FIGURE 73

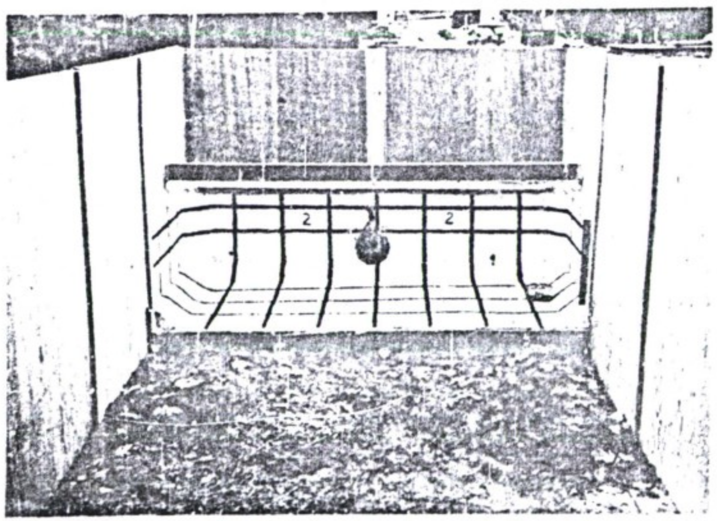
SCALED BAY TEST SET-UPS



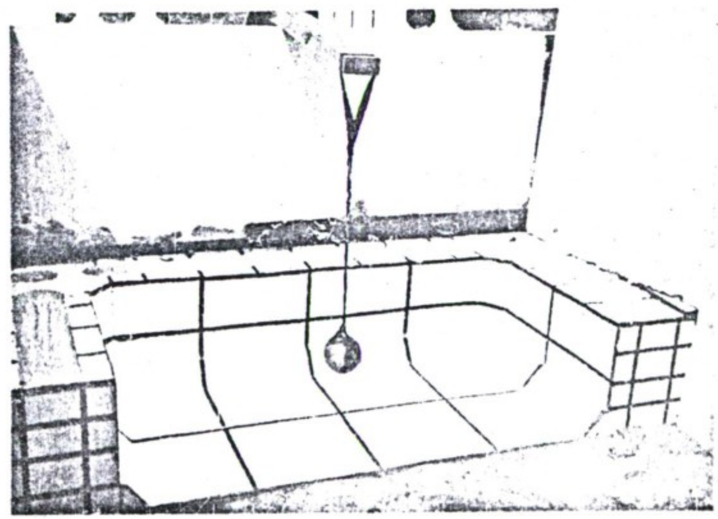
TEST SET-UP 1/3 SCALE BAY



TEST SET-UP 1/8 SCALE BAY



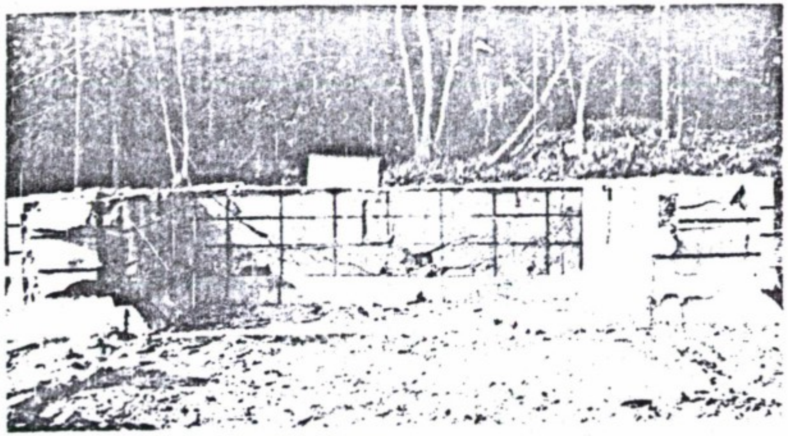
TEST SET-UP 1/5 SCALE BAY



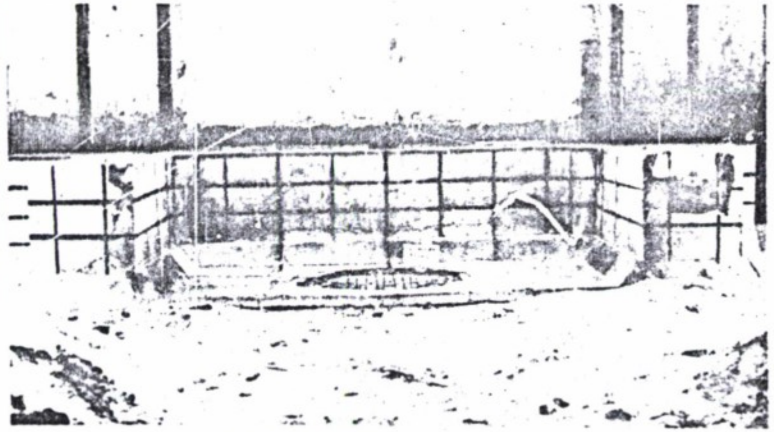
TEST SET-UP 1/10 SCALE BAY

FIGURE 77

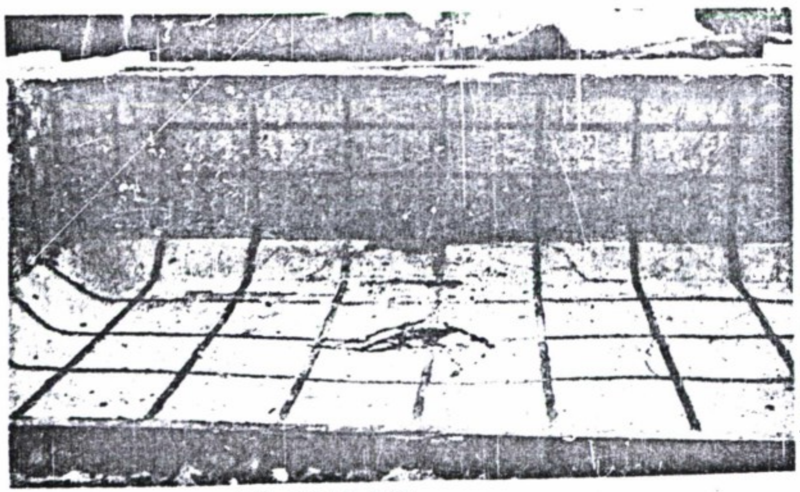
SCALED BAY TESTS ROUND 1 (2,000 LBS. HE EQUIVALENT)
DONOR SIDE



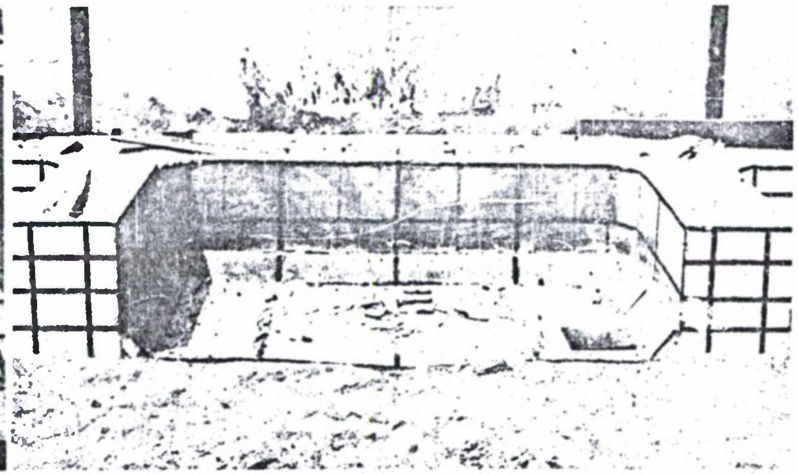
1/3 SCALE BAY
Z = 0.775, W = 75 LBS.



1/8 SCALE BAY
Z = 0.79, W = 4.0 LBS.



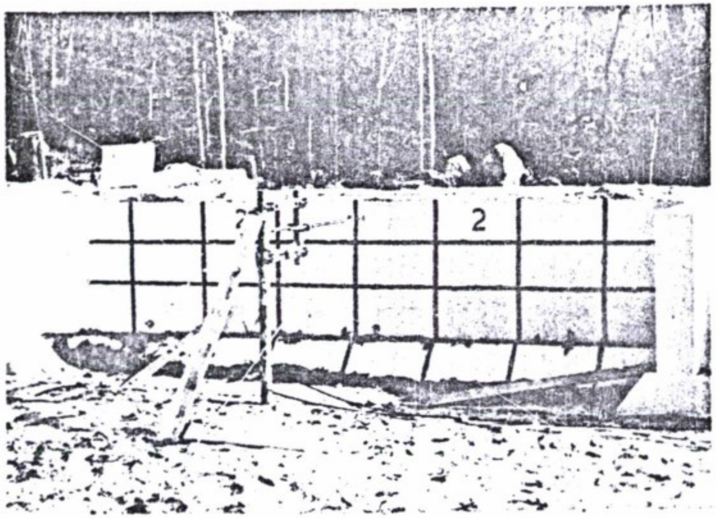
1/5 SCALE BAY
Z = 0.785, W = 16 LBS.



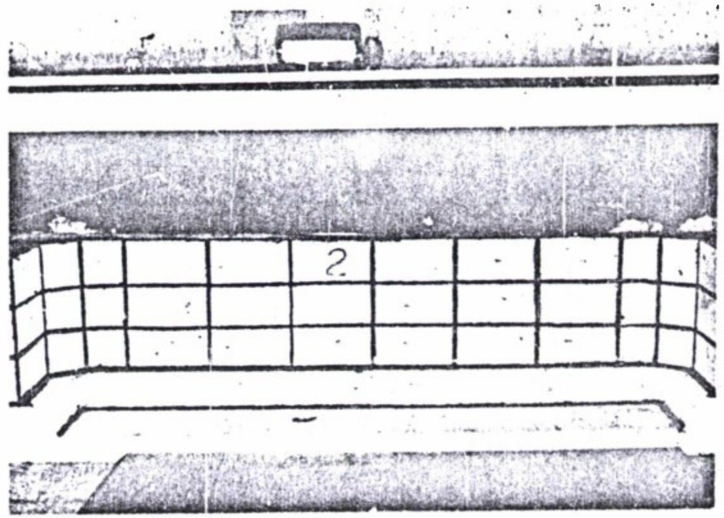
1/10 SCALE BAY
Z = 0.8, W = 2.0 LBS.

FIGURE 78
INSIDE VIEW OF SCALED BAY STRUCTURE

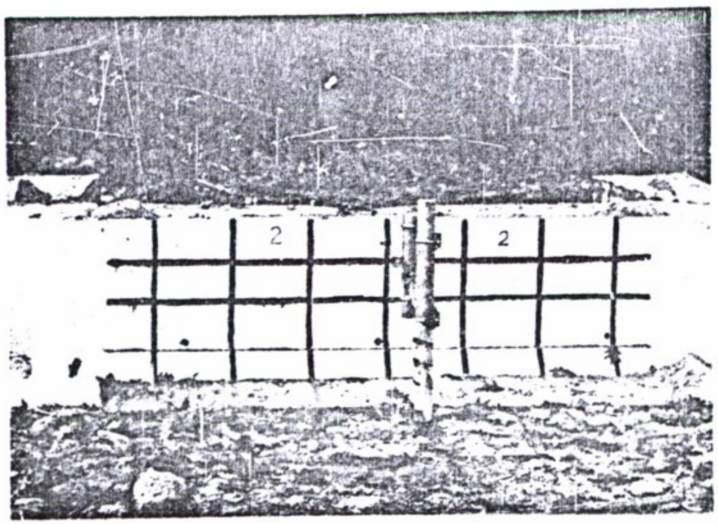
SCALED BAY TESTS ROUND 1 (2.000 LBS. HE EQUIVALENT)



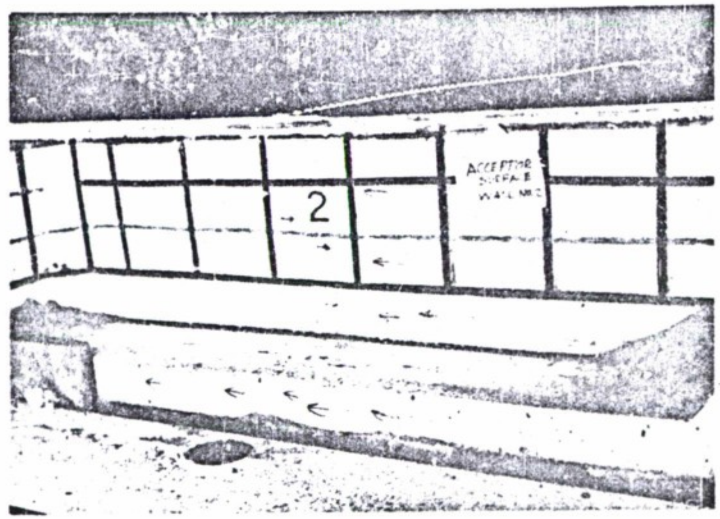
1/3 SCALE BAY $Z = 0.775$ $W = 75$ LBS.



1/8 SCALE BAY $Z = 0.79$ $W = 4.0$ LBS.



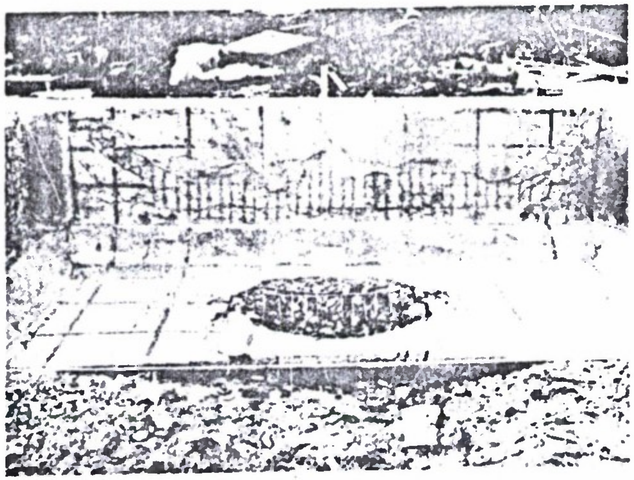
1/5 SCALE BAY $Z = 0.785$ $W = 16$ LBS.



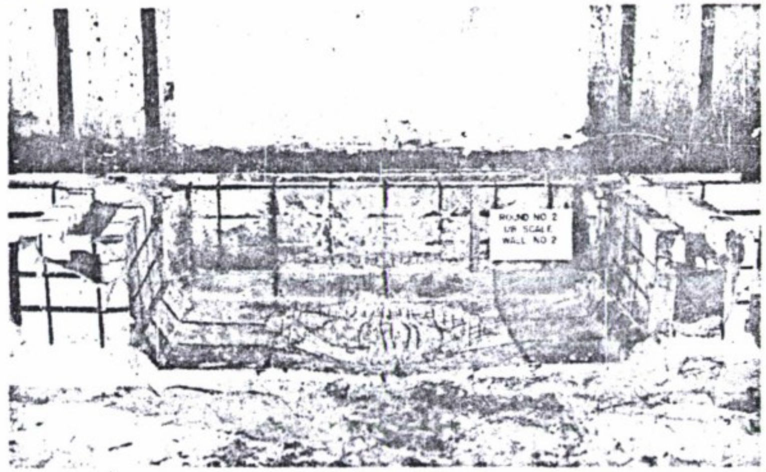
1/10 SCALE BAY $Z = 0.8$ $W = 2.0$ LBS.

FIGURE 73
OUTSIDE VIEW OF SCALED BAY STRUCTURE

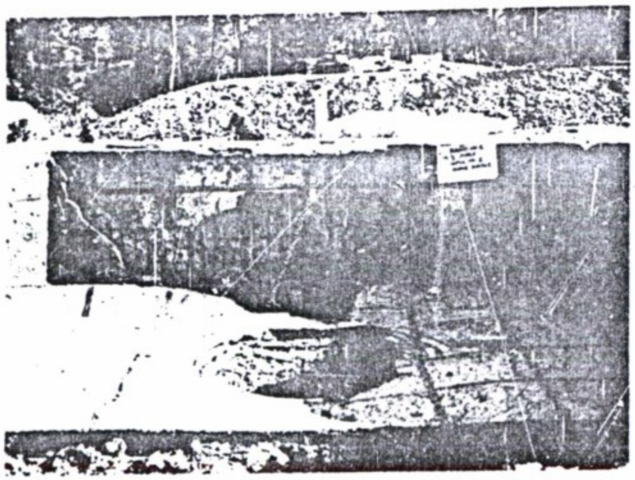
SCALED BAY TESTS ROUND 2 (3,000 LBS. HE EQUIVALENT)
DONOR SIDE



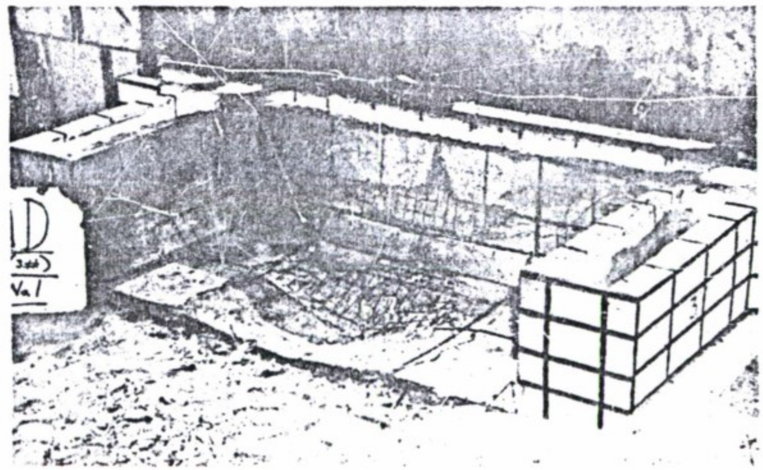
1/3 SCALE BAY
Z = 0.68, W = 112.5 LBS.



1/8 SCALE BAY
Z = 0.69, W = 6.0 LBS.



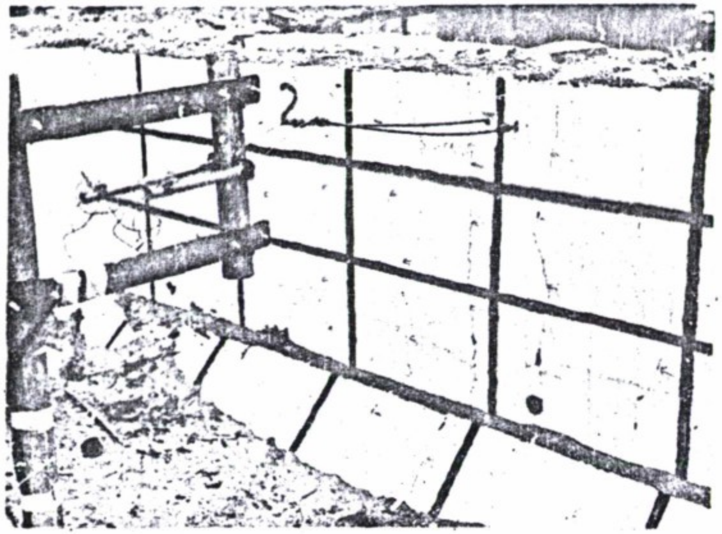
1/5 SCALE BAY
Z = 0.688, W = 24 LBS.



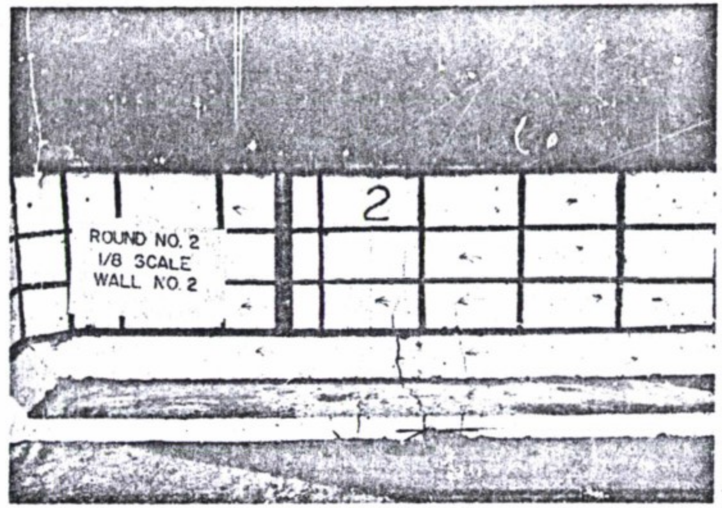
1/10 SCALE BAY
Z = 0.675, W = 3.24 LBS.

FIGURE 80
INSIDE VIEW OF SCALED BAY STRUCTURE

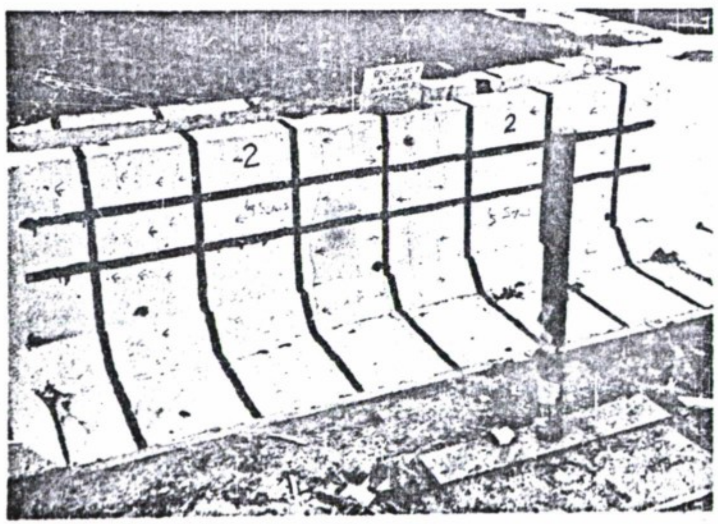
SCALED BAY TESTS ROUND 2 (3,000 LBS. HE EQUIVALENT)



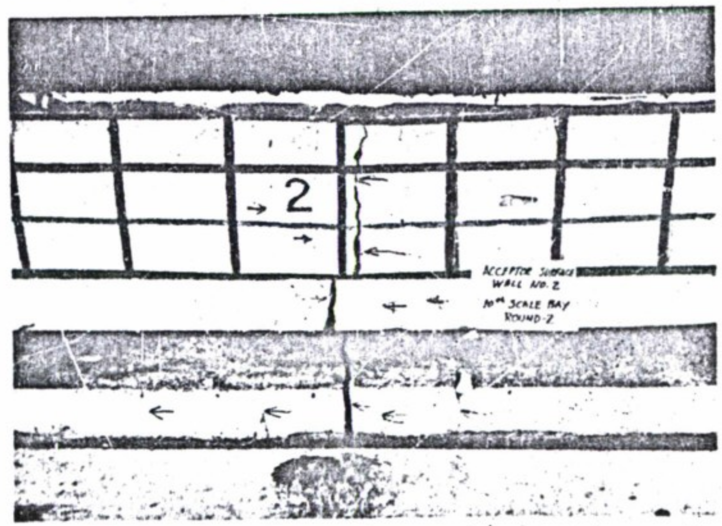
1/3 SCALE BAY Z = 0.68 W = 112.5 LBS.



1/8 SCALE BAY Z = 0.69 W = 6.0 LBS.



1/5 SCALE BAY Z = 0.688 W = 24 LBS.

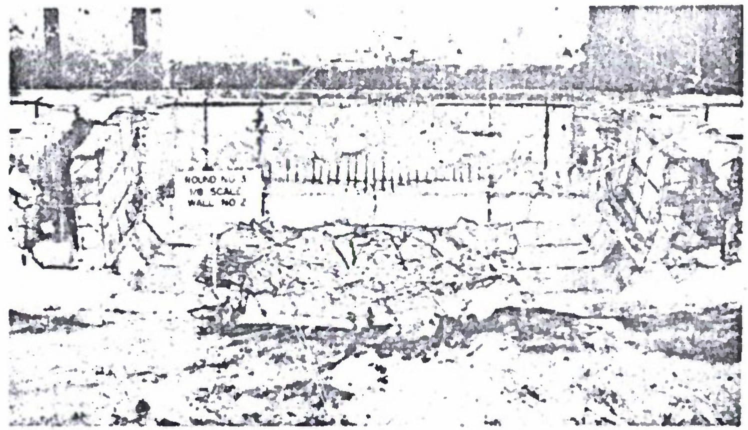


1/10 SCALE BAY Z = 0.675 W = 3.24 LBS.

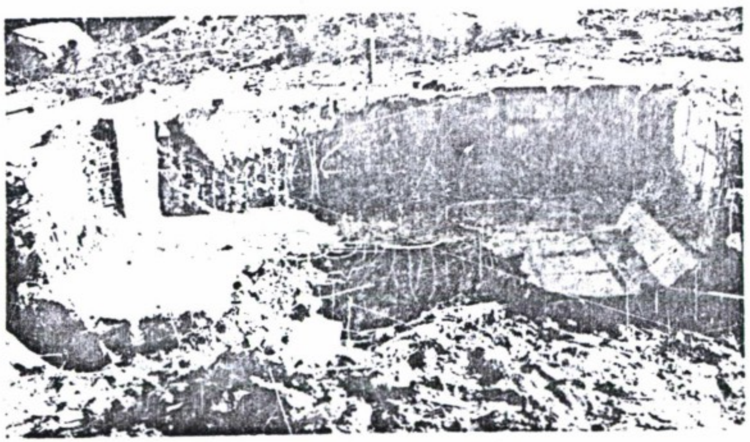
FIGURE 61
OUTSIDE VIEW OF SCALED BAY STRUCTURE

SCALED BAY TESTS ROUND 3 (5,000 LBS. HE EQUIVALENT)
DONOR SIDE

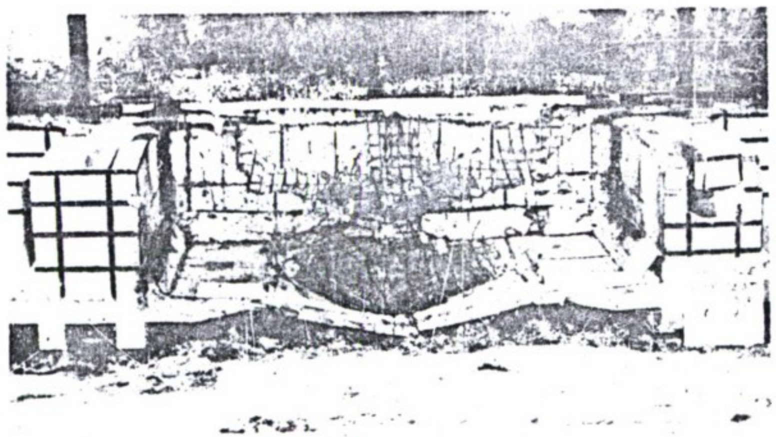
1/3 SCALE BAY
Z = 0.53, W = 112.5 LBS.



1/8 SCALE BAY
Z = 0.58, W = 10.0 LBS.



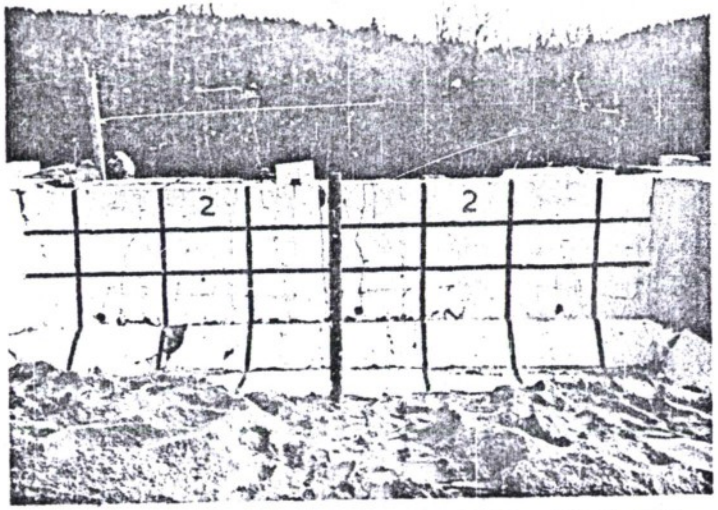
1/5 SCALE BAY
Z = 0.58, W = 40 LBS.



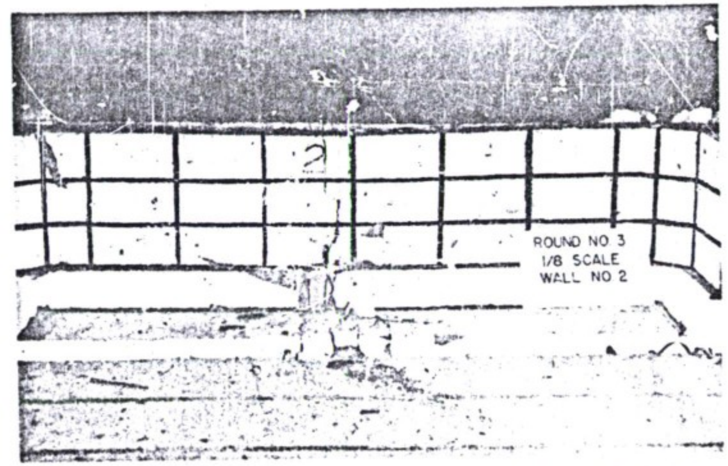
1/10 SCALE BAY
Z = 0.62, W = 4.24 LBS.

FIGURE 82
INSIDE VIEW OF SCALED BAY STRUCTURE

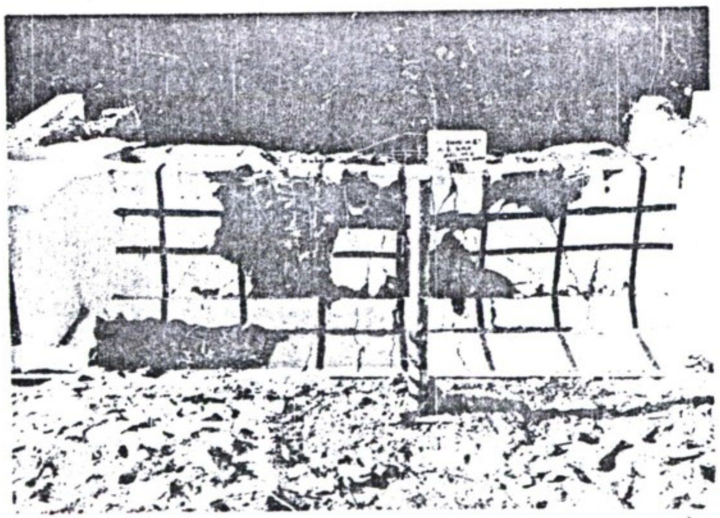
SCALED BAY TESTS ROUND 3 (5,000 LBS. HE EQUIVALENT)



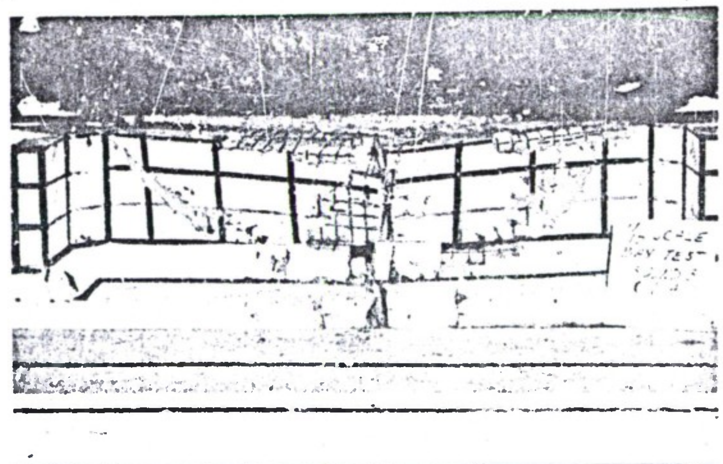
1/3 SCALE BAY Z = 0.53 W = 112.5 LBS.



1/8 SCALE BAY Z = 0.58 W = 10.0 LBS.



1/5 SCALE BAY Z = 0.58 W = 40 LBS.



1/10 SCALE BAY Z = 0.62 W = 4.24 LBS.

FIGURE 63
OUTSIDE VIEW OF SCALED BAY STRUCTURE

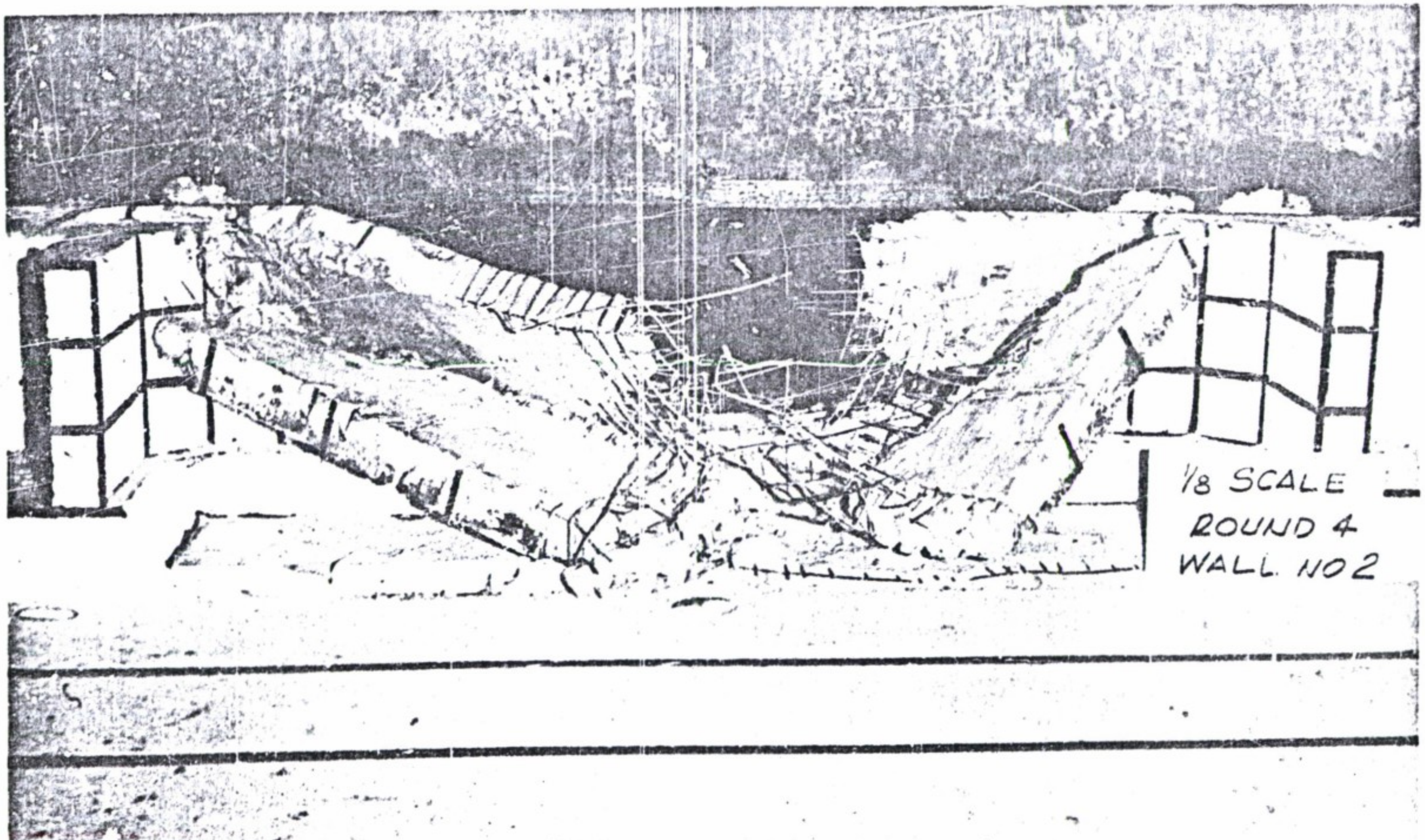


FIGURE 84A

OUTSIDE VIEW OF 1/8TH SCALE BAY STRUCTURE

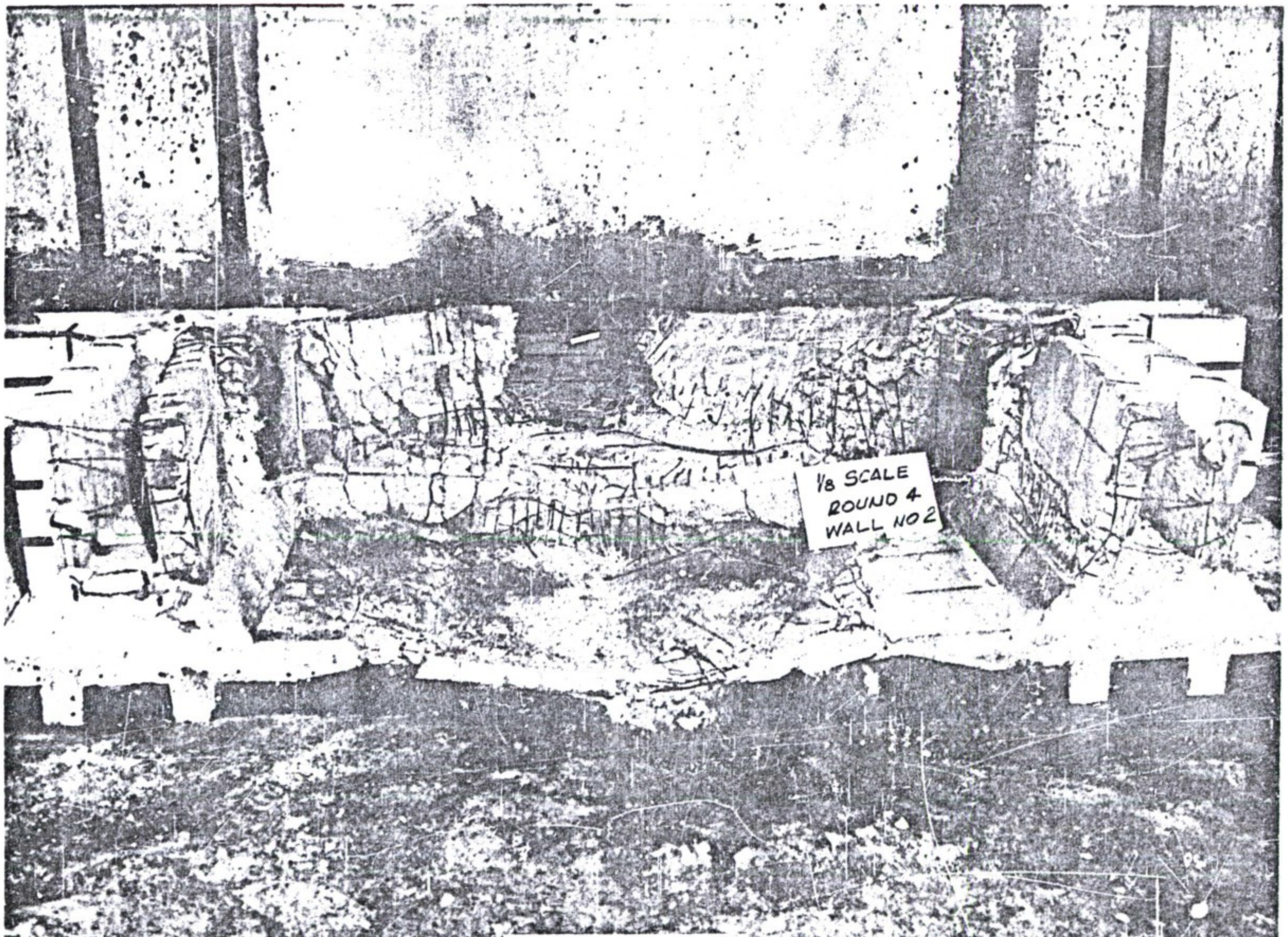


FIGURE 84B

INSIDE VIEW OF 1/8TH SCALE BAY STRUCTURE

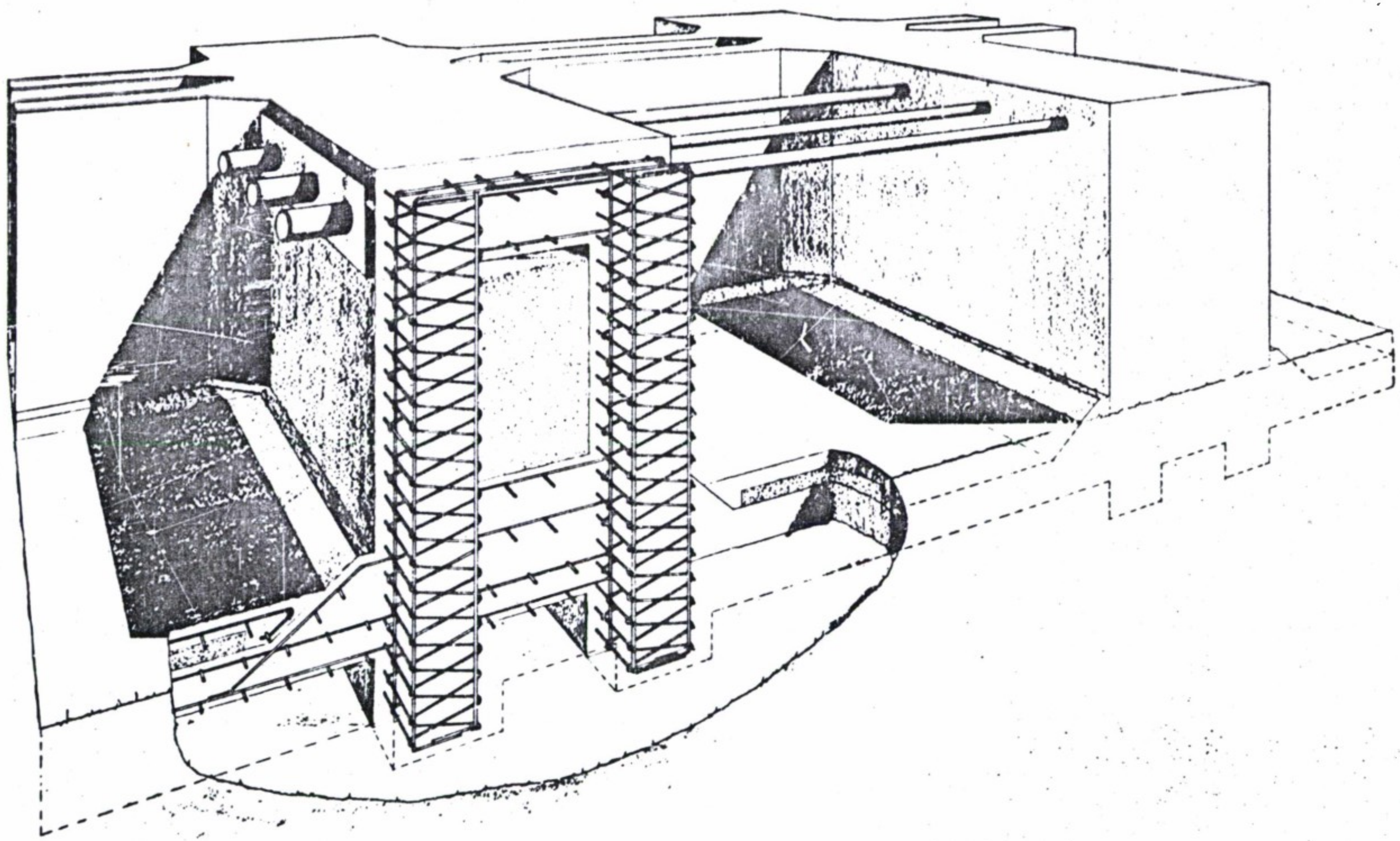
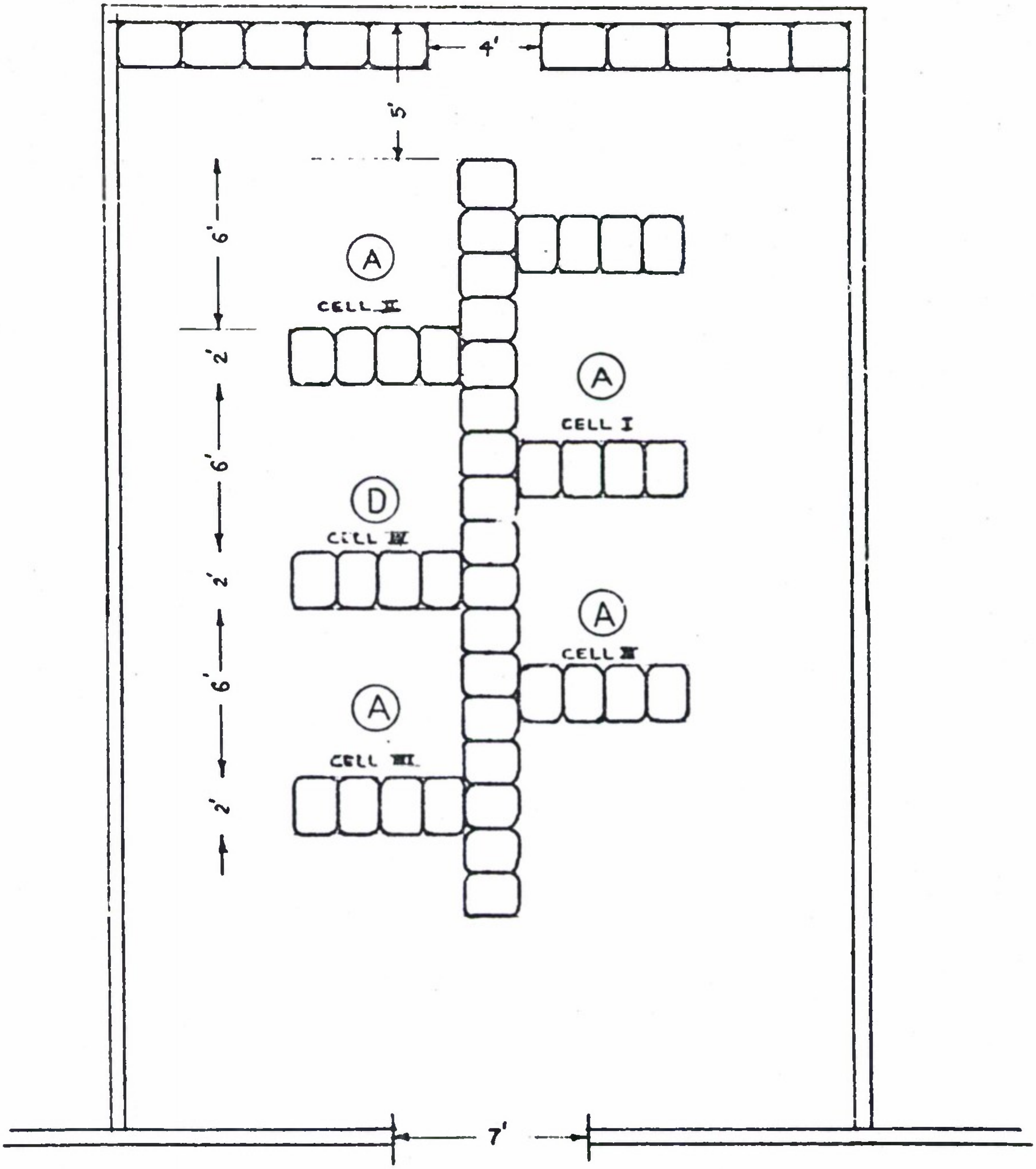


FIGURE 85
ONE-THIRD SCALE MODIFIED C-13 CUBICLE



1. ALL WALLS 2' THICK
2. WALL HEIGHT - 6'
3. NO PLYWOOD WALL FORMS
4. BLAST PRESSURE GAUGES IN ALL DONOR AND ACCEPTOR CELLS.

A - ACCEPTOR
D - DONOR

FIGURE 86

IGLOO COMPARTMENT LAYOUT

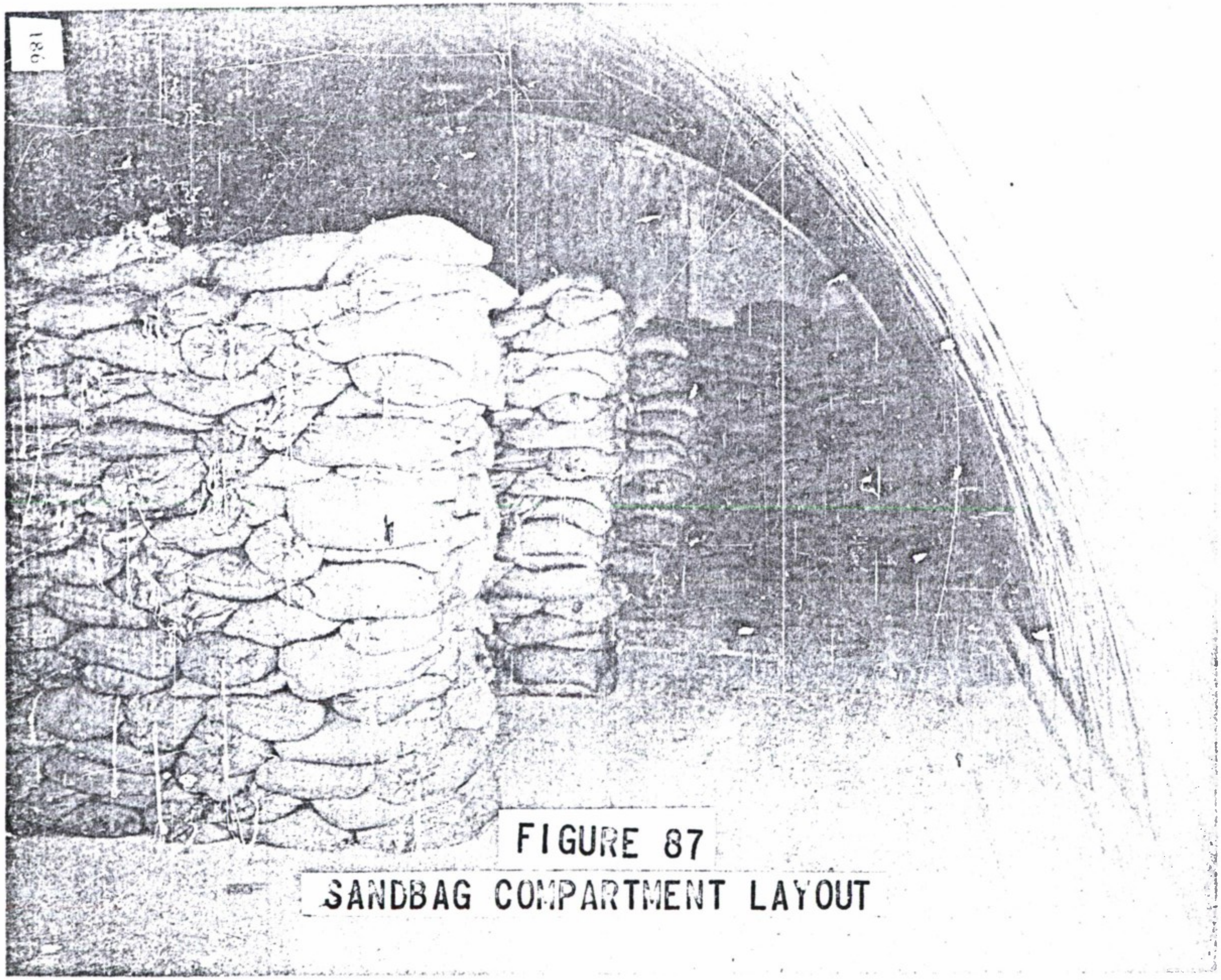


FIGURE 87

SANDBAG COMPARTMENT LAYOUT

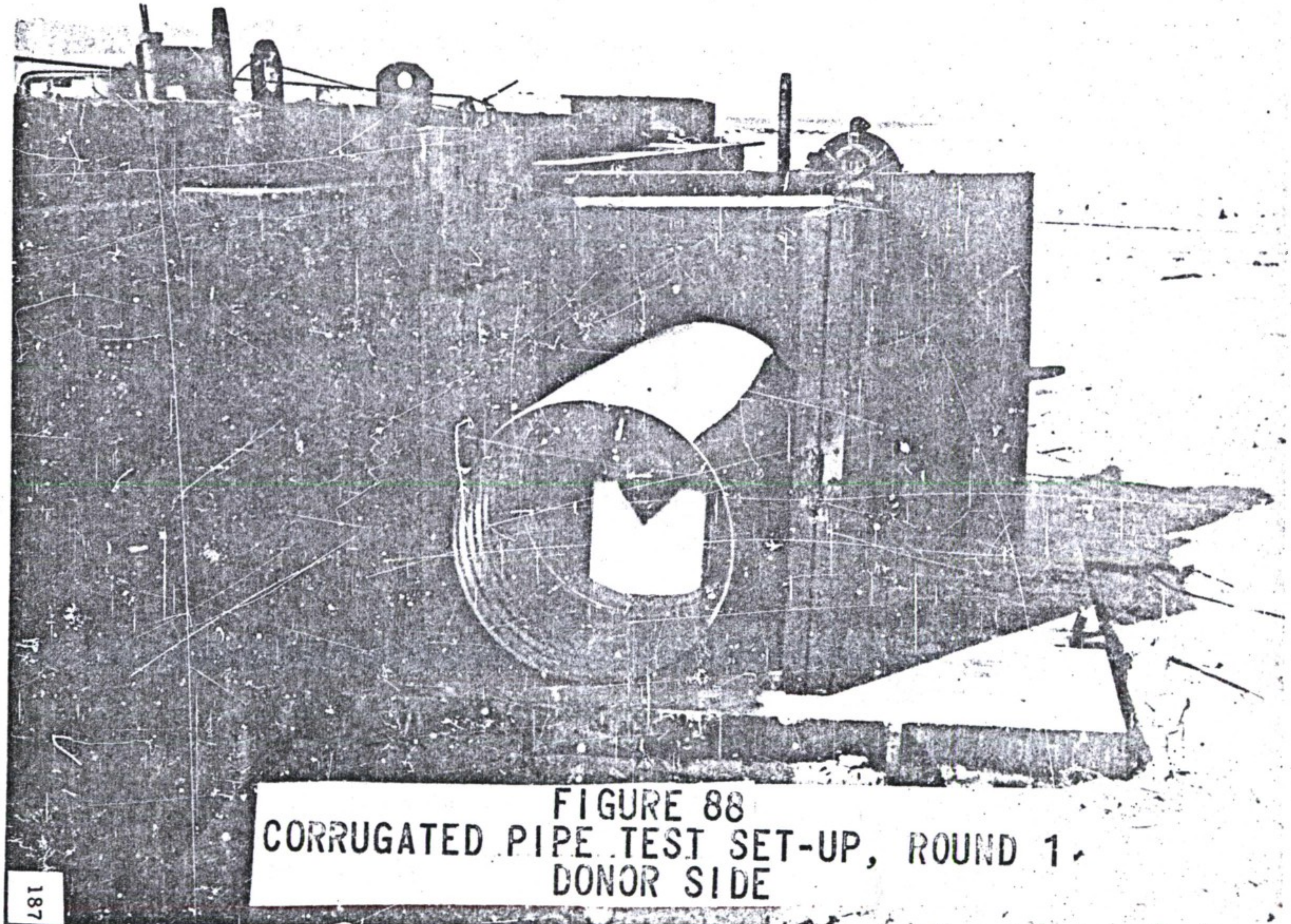


FIGURE 88
CORRUGATED PIPE TEST SET-UP, ROUND 1
DONOR SIDE

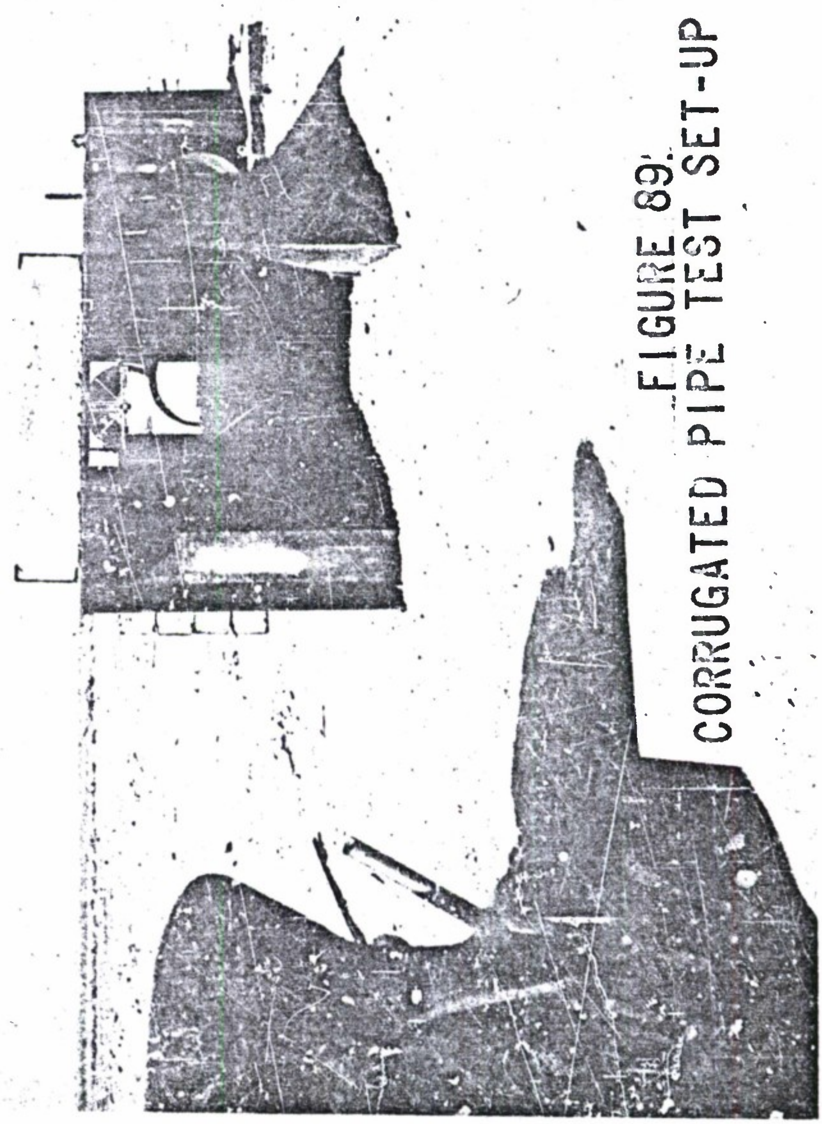


FIGURE 89.
CORRUGATED PIPE TEST SET-UP

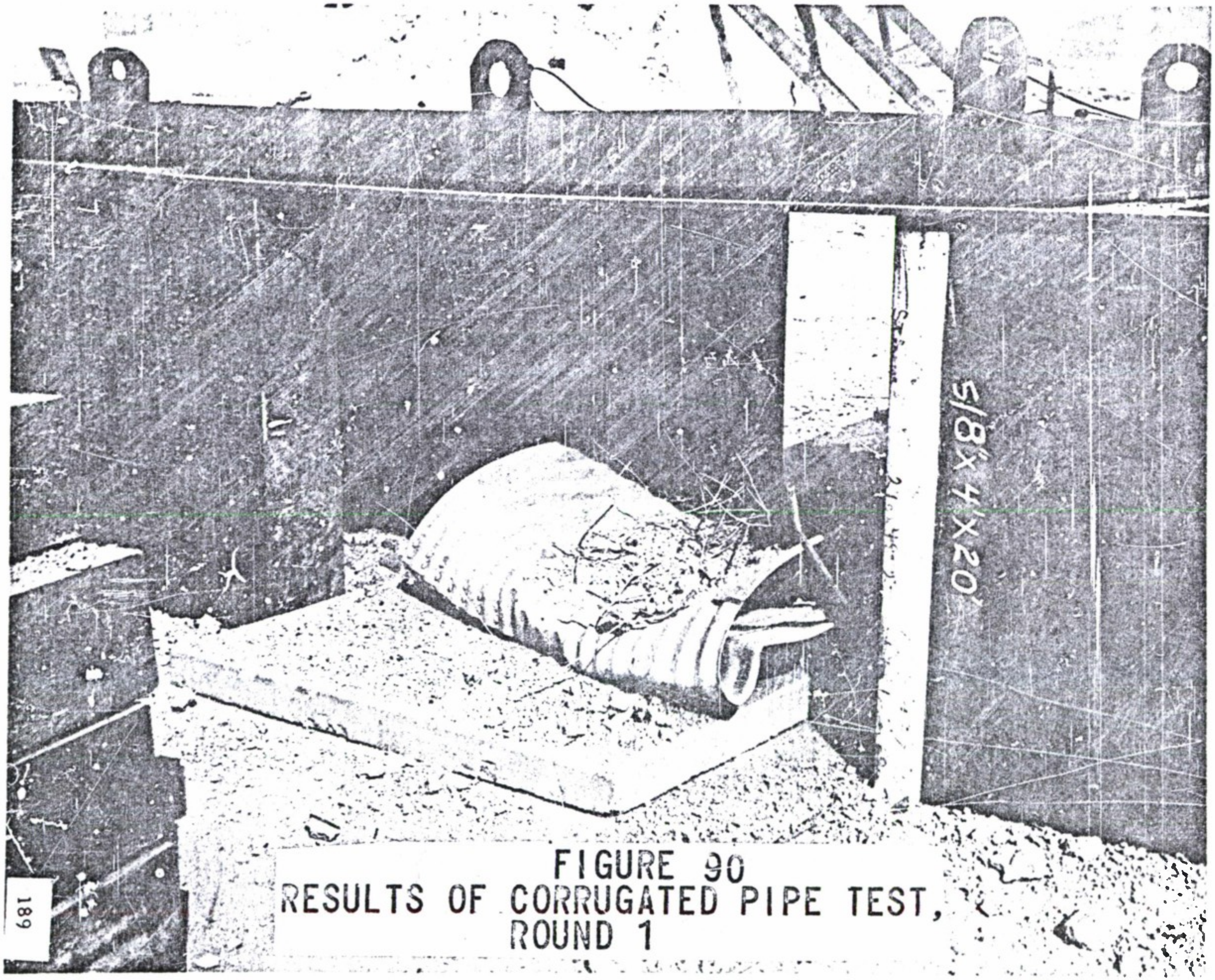


FIGURE 90
RESULTS OF CORRUGATED PIPE TEST,
ROUND 1

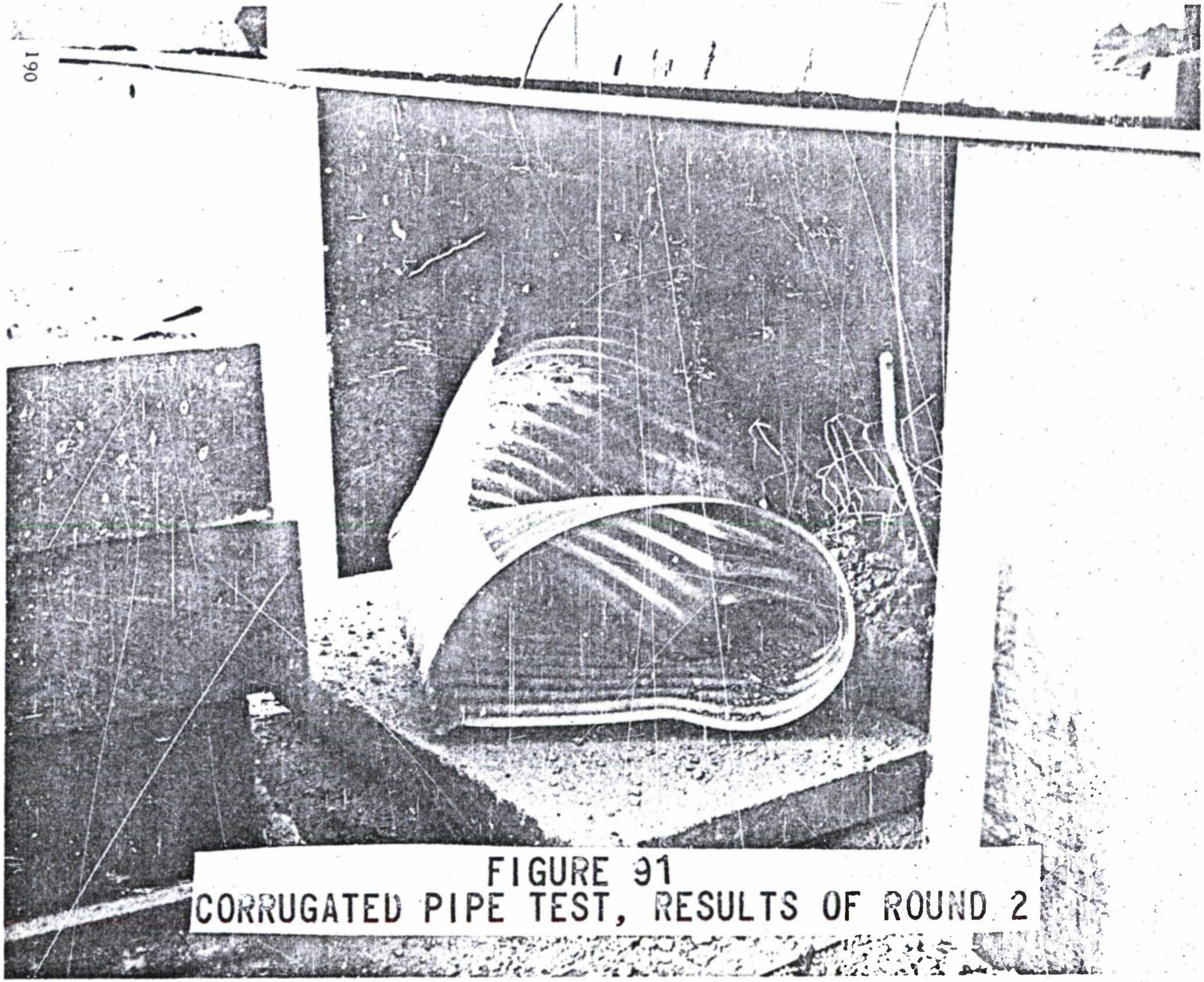
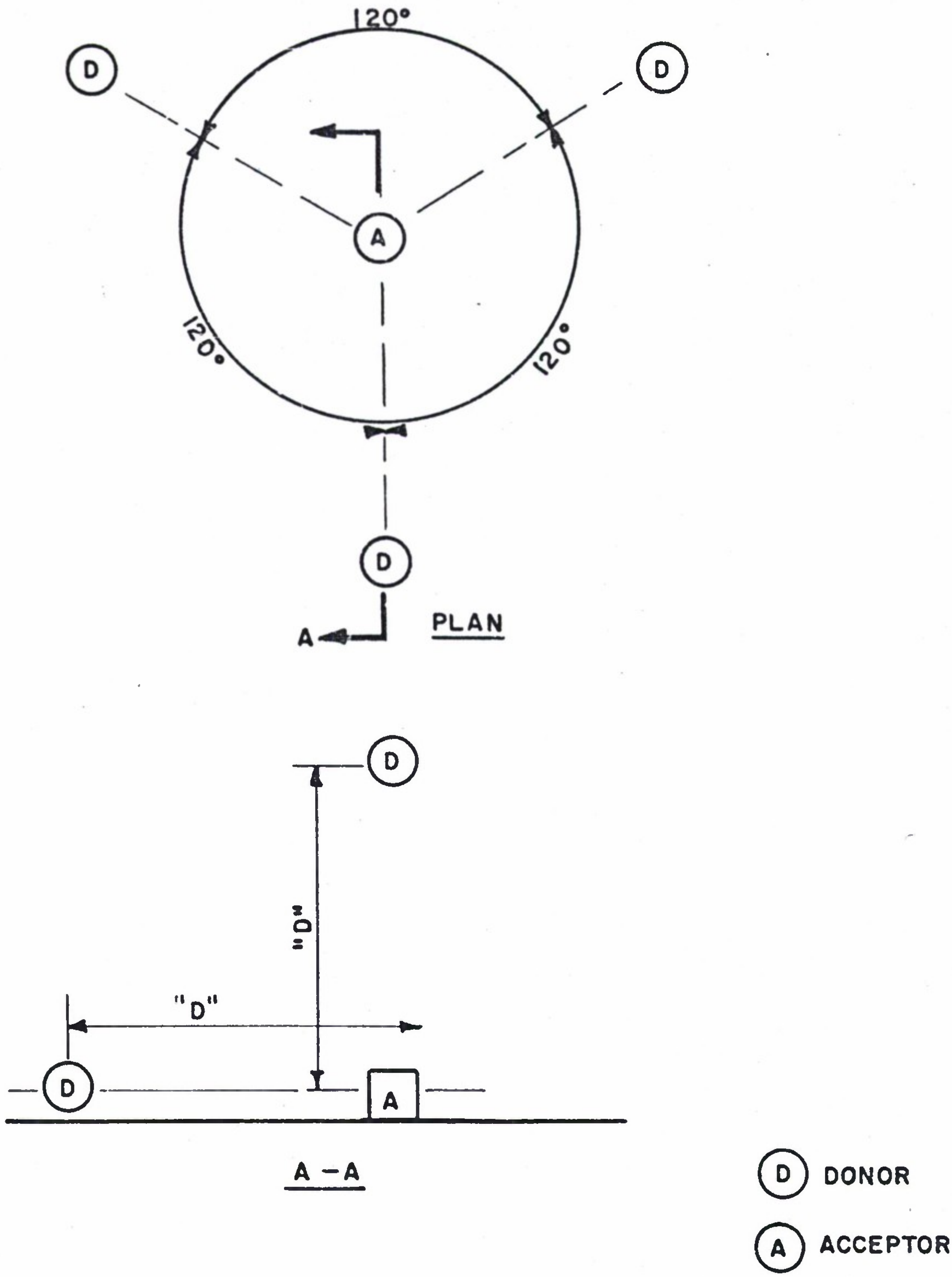


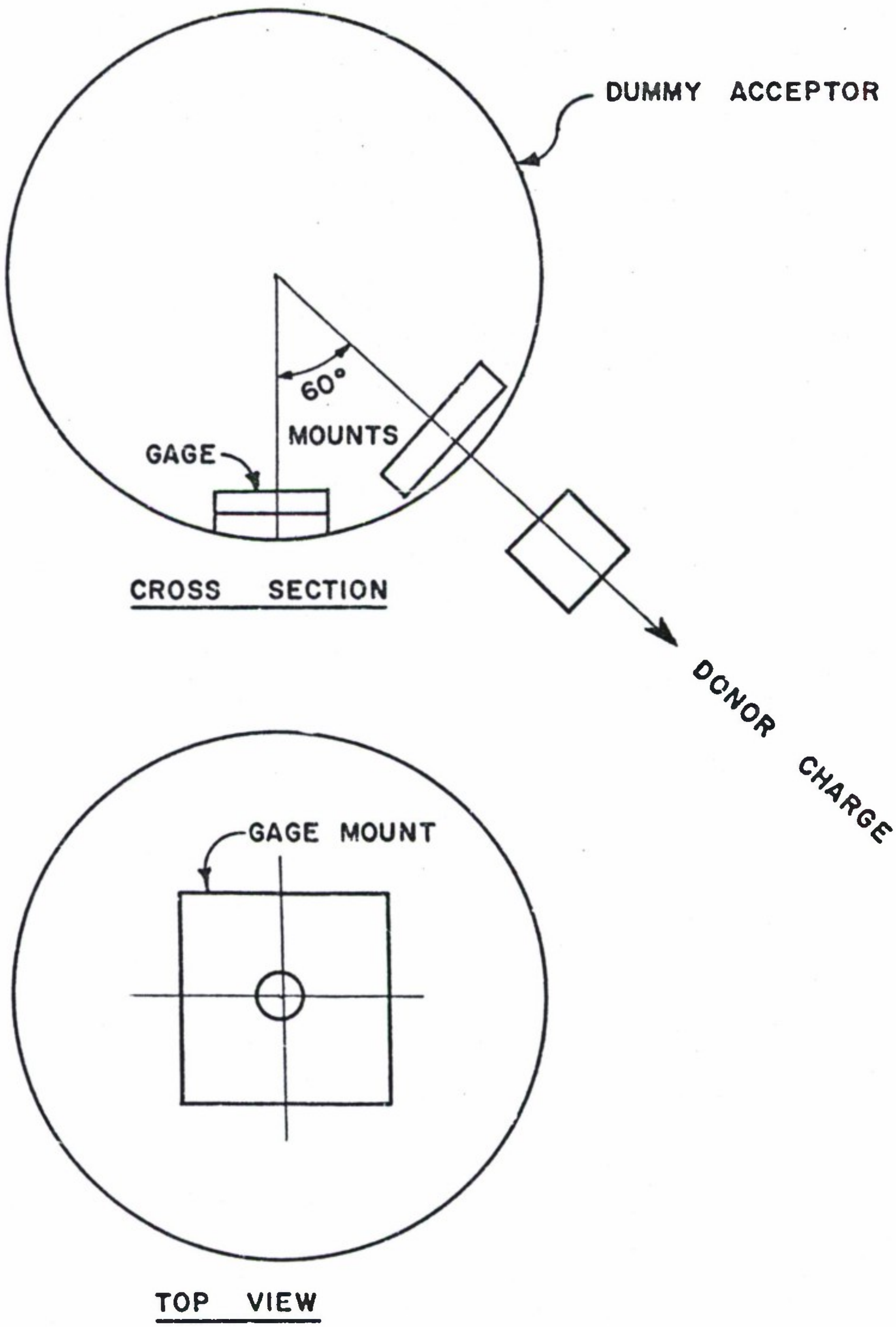
FIGURE 91
CORRUGATED PIPE TEST, RESULTS OF ROUND 2



Layout: For Acceptor Sensitivity Evaluation

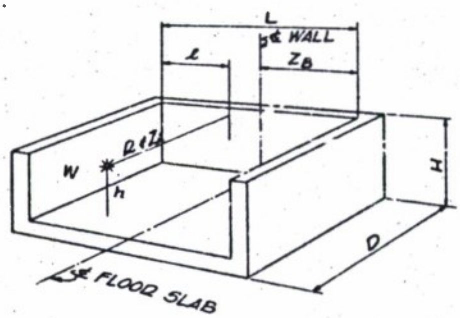
"D" Will Be Varied From Test To Test To Produce The Desired Overpressure At The Acceptor.

FIGURE 92

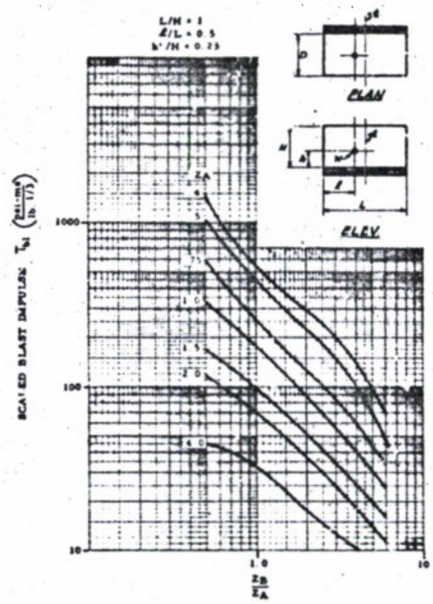


Gage Placement For Acceptor Sensitivity Test Calculation.

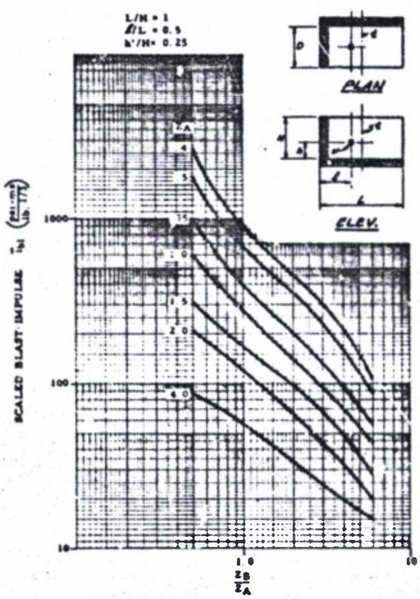
FIGURE 93



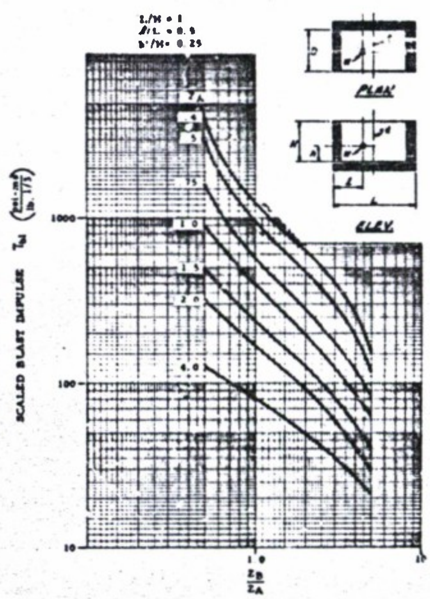
CUBICLE PARAMETERS



TYPICAL IMPULSE LOAD CURVES
(CANTILEVER WALL)



TYPICAL IMPULSE LOAD CURVES
(SIDE WALL)



TYPICAL IMPULSE LOAD CURVES
(BACK WALL)

FIGURE 94

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3. REPORT TITLE
SUPPORTING STUDIES, JANUARY-DECEMBER 1965 REPORT NO. 8: SAFETY DESIGN CRITERIA FOR USE IN ENGINEERING OF EXPLOSIVE FACILITIES AND OPERATIONS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, initial)
RINDNER, Richard M.
WACHTELL, Stanley
SAFFIAN, Leon W.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1966	202	11

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report 3484 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Picatinny Arsenal U.S. Army Munitions Command Dover, New Jersey

13. ABSTRACT

This report presents a summary of activities from January-December 1965 on the supporting studies to establish a Safety Design Criteria Program under the technical management of Picatinny Arsenal. Work performed in these areas is described: A model scale slab test program (1/3 and 1/10 scale) to investigate the response of reinforced concrete to blast loads; a model scale bay test program to evaluate the explosive capacity of a bay structure and to establish the validity of scaling; a 1/3 scale modified C-13 cubicle test to demonstrate the use of new design and construction techniques; a full-scale test program to complete the investigation for compartmenting igloos for safe storage of small weapons, and development of new impulse curves in a cubicle type structure.

This work is being done by the Ammunition Engineering Directorate's Process Engineering Laboratory for the Armed Services Explosive Safety Board.

DD FORM 1 JAN 64 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Supporting Studies (Annual Report -- 1965)						
Safety Design Criteria Program						
Engineering of Explosive Facilities and Operations						
Model Scale Concrete Slab Tests						
Model Scale Bay Tests						
Modified C-13 Cubicle Test						
Armed Services Explosive Safety Board						
Blast Measurement and Testing						

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